Effluent Polishing by Filtration Through Activated Alumina

Volume II

Research Report No. 40

Research Report No. 40 Effluent Polishing by Filtration Through Activated Alumina Volume II

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**esearch Program for the Abatement of Municipal Pollution
under Provisions of the Canada-Ontario Agreement
on Great Lakes Water Quality**

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RESEARCH REPORTS

These RESEARCH REPORTS describe the results of investigations funded under the Research Program for the Abatement of Municipal Pollution within the Provisions of the Canada-Ontario Agreement on Great Lakes Water Quality. They provide a central source of information on the studies carried out in this program through in-house projects by both Environment Canada and the Ontario Ministry of the Environment, and contracts with municipalities, research institutions and industrial organizations.

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EFFLUENT POLISHING BY FILTRATION THROUGH ACTIVATED ALUMINA

VOLUME II

(March, 1975)

by

Pollutech Pollution Advisory Services Ltd.
Oakville, Ontario

RESEARCH PROGRAM FOR THE ABATEMENT
OF MUNICIPAL POLLUTION WITHIN THE
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ABSTRACT

Chemically pretreated secondary effluent from the Waterloo Water Pollution Control Plant was polished in pilot scale activated alumina columns. Various regeneration modes for removal of phosphorus from the saturated alumina were investigated. The feasibility of lime treatment of the regenerant solutions to allow continued reuse of the caustic was evaluated. Capital and operating cost estimates were developed based on the findings of the study.

All phases of the process, phosphorus adsorption, sodium hydroxide regeneration and lime precipitation were found to be technically feasible. The adsorptive capacity of fresh activated alumina was approximately 4.75 mg P/g Al_2O_3, but was significantly reduced after several saturation-regeneration cycles. Once through elution with 15 bed volumes of 1N NaOH was determined to be the most efficient regeneration mode. Continuous recirculation of small volumes of caustic did not improve the regeneration efficiency. Activated alumina losses during regeneration were minimal and did not account for the loss of adsorptive capacity of the bed. Lime treatment of the regenerant solutions at a dosage of 8 g/l effectively removed the phosphorus to allow reuse of the sodium hydroxide solution. However, continued lime addition adversely affected the settling properties of the precipitate and further studies are required in this area.

Capital cost of the activated alumina process for the treatment of 1 MIGPD of chemically pretreated secondary effluent was estimated to be $141,000. Operating costs were $113.70 per MIG. These costs are significantly higher than the estimates based on the laboratory results due to the necessity for prefiltration of the column feed, lower adsorptive capacity of the activated alumina and higher alumina make-up requirements.

RÉSUMÉ

On a fait, en unité pilote, dans des colonnes d'alumine activée, le traitement final de l'effluent secondaire de l'usine de traitement des eaux usées de Waterloo; cet effluent avait été préalablement traité chimiquement. On a étudié différentes méthodes permettant de réactiver l'alumine en en extrayant le phosphore et évalué la possibilité de traiter à la chaux les solutions de soude caustique utilisées à cette fin en vue de les utiliser de façon répétée. Grâce aux observations, on a pu déterminer quels seraient les coûts d'immobilisations et d'exploitation du procédé.

Toutes les étapes de ce procédé, c'est-à-dire adsorption du phosphore, régénération de l'hydroxyde de sodium, précipitation de la chaux, se sont révélées techniquement possibles. Le pouvoir d'adsorption de l'alumine activée fraîche était d'environ 4,75 mg de P/g de Al_2O_3, mais il a considérablement diminué après quelques cycles de saturation et de réactivation. Le mode de réactivation le plus efficace a été le passage à un seul cycle d'un volume de NaOH 1N égal à 15 fois celui de l'alumine. La recirculation en maigres volumes de NaOH n'a pas amélioré l'efficacité de la réactivation. Les pertes d'alumine, à cette étape étaient minimes et n'ont aucunement contribué à l'abaissement du pouvoir d'adsorption. La régénération des solutions réactivantes, à raison de 8 g/l de chaux a permis d'éliminer le phosphore de la solution de NaOH et de réutiliser cette dernière. Toutefois, l'addition répétée de chaux a eu un effet contraire sur la décantabilité du précipité et des études sont nécessaires en ce domaine.

Le coût en capital du procédé de traitement à l'alumine activée de 1 million de gallons impériaux d'effluent secondaire préalablement traité chimiquement, et par jour, a été estimé à $141,000. Les coûts d'exploitation seraient de $113.70 par million de gallons impériaux. Ces coûts sont

notablement plus élevés que les coûts estimatifs obtenus à partir des résultats de laboratoire, à cause de la filtration préalable et obligatoire de l'effluent dirigé vers les colonnes, du pouvoir d'adsorption inférieur de l'alumine activée et des quantités nécessaires d'appoint de cette dernière, supérieures.

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CONCLUSIONS

From the results of the pilot plant investigation of the activated alumina adsorption process, the following conclusions can be drawn:

- All phases of the process, phosphorus adsorption, sodium hydroxide regeneration, and lime precipitation are technically feasible.
- Chemically pretreated secondary effluent can be polished to low phosphorus concentrations. The minimum orthophosphate concentration attainable during this study was approximately 0.10 mg P/l.
- The adsorptive capacity of fresh activated alumina was approximately 4.75 mg P/g Al_2O_3. However, continued saturation and regeneration of the alumina resulted in a reduction in the phosphorus capacity to about 2.0 mg P/g Al_2O_3 after four to six cycles. Based on the results obtained at the Waterloo Water Pollution Control Plant, it is expected that an operational adsorptive capacity of 3.0 mg P/g Al_2O_3 could be maintained at a fresh alumina make-up of 10 percent per cycle.
- The variations in feed quality experienced during the study had the most noticeable effect on the performance of the activated alumina columns.
- All of the regeneration modes investigated were successful in removing adsorbed phosphorus from the saturated alumina columns. Recirculation of the regenerant through the bed does not improve the phosphorus recovery, as the majority

of the recoverable phosphorus is removed during the initial contact period.

- Once through elution with 15 bed volumes of 1N sodium hydroxide resulted in the most efficient regeneration in terms of phosphorus removal, caustic requirements and alumina losses.
- Activated alumina losses due to caustic regeneration were only about one percent by weight. Losses from the regeneration of fresh alumina were substantially higher than the losses from previously regenerated alumina.
- The addition of lime to phosphorus laden regenerant solutions effectively reduced the phosphorus content of the caustic and allowed reuse of the sodium hydroxide. However, continued application of lime to the regenerant solution resulted in a non-settling sludge and further studies would be required to determine the long term effect on the settling properties of the solids.
- Lime treatment of the caustic solutions did not reduce the regenerative capacity when large volumes of sodium hydroxide were used. Low phosphorus recovery was experienced during once through elution with regenerant solutions which had been lime treated more than once. The effect of continued lime treatment of the regenerative properties of the caustic would require further investigation.
- Capital cost for the treatment of 1 MIGPD from 1 mg P/l to 0.20 mg P/l is estimated to be $141,000. Operating costs for the process are approximately $113.70 per MIG.

- The cost estimates indicate that effluent polishing with activated alumina is more expensive than originally calculated from the laboratory results. The increased cost is due to the necessity of filtering the secondary effluent, the reduced adsorptive capacity of the alumina and the more rapid reduction in the capacity per cycle.

1. INTRODUCTION

The International Joint Commission (IJC), following intensive studies on the water quality of the Great Lakes, has determined that control of phosphorus discharges from municipal water pollution control plants is necessary to retard the process of eutrophication. Therefore, under the terms of the Canada - U.S. Agreement, a rigorous program of phosphorus removal has been instituted to reduce the phosphorus content of effluents discharged into the Great Lakes from municipal water pollution control plants to an average level of 1 mg/l. At the present level of technology, the most economical means of attaining this goal is the precipitation of the sewage phosphorus with a metal salt, i.e. alum, ferric chloride or lime, and subsequent sedimentation of the phosphate floc in the treatment plant clarifiers.

The effect of this reduction in the nutrient load on the quality of the receiving waters can be only estimated. Studies are continuing in an attempt to define precisely the phosphorus concentration in an aquatic environment which will not adversely affect the natural ecological balance of the system. Based on the results of these studies, it may be necessary to further reduce the phosphorus content of treatment plant effluents, particularly in areas with high recreational potential.

Chemical precipitation has proven to be effective in reducing the phosphorus content of treated sewage to levels below 1 mg/l; however, the cost of the process rapidly increases as the discharge requirements become more strict. Numerous studies have indicated that phosphorus adsorption from treated sewage using activated alumina is technically feasible. Preliminary evaluations of the relative economics of conventional chemical treatment for phosphorus removal to low effluent concentrations, as opposed to the use of a combination of conventional chemical treatment and effluent polishing with activated alumina, indicate that the latter process could be a viable alternative.

In order to better define the operating conditions and economics of a combined precipitation-adsorption process for phosphorus removal, Pollutech Pollution Advisory Services Limited was retained under the provisions of the Canada-Ontario Agreement on Great Lakes Water Quality to study the pilot scale operation of an activated alumina system treating chemically precipitated secondary effluent. This report summarizes the results of the pilot plant study carried out at the Waterloo Water Pollution Control Plant during the fall and winter of 1974-75.

2. TECHNICAL BACKGROUND

An extensive review of the literature was included in Volume I of "Effluent Polishing by Filtration Through Activated Alumina", (March 15, 1974) which provided a detailed technical background for the use of activated alumina for removal of phosphorus from aqueous solutions. This section is intended as a review of the results of Pollutech's laboratory investigation of the combined chemical precipitation-adsorption process for phosphorus removal from secondary effluents.

The laboratory program involved pretreatment of secondary effluent from the Oakville Water Pollution Control Plant with alum to produce a feed of known residual phosphorus concentration. The resultant feeds were applied at fixed rates to the laboratory scale fluidized beds of activated alumina and the column effluents monitored. Regeneration of the spent activated alumina with sodium hydroxide solutions was also investigated.

The results of the laboratory study can be summarized as follows:

- Activated alumina was capable of reducing the phosphorus content of secondary effluents to very low levels.
- The performance of the activated alumina columns was affected by the contact time between the secondary effluent and the alumina particles, and the phosphorus content of the feed.
- The effective capacity of the activated alumina was approximately 6.5 mg P/g Al_2O_3. Higher capacities could be attained, but at the expense of deteriorating effluent quality.
- Exhausted activated alumina could be restored to its original performance by regeneration with

either 1N or 2N sodium hydroxide. The effectiveness of the regeneration appeared to be dependent on the liquid-solid contact time.

- Small fluctuations in the feed phosphorus concentration experienced during the laboratory study did not appear to significantly affect the performance of the activated alumina.
- Alum addition alone was capable of reducing the phosphorus content of the secondary effluent to levels below 1 mg/l; however, this degree of treatment required a significant increase in chemical dosage and resulted in a significant increase in sludge production.
- A combined treatment system employing chemical precipitation and activated alumina adsorption was found to be technically feasible and economically attractive if a reduction in the effluent phosphorus concentration to below 0.5 mg/l were required.

3. OBJECTIVES

The primary objectives of this study were to assess the performance of the activated alumina adsorption process under pilot scale conditions and to estimate the economical feasibility of the system. Specifically, the objectives were as follows:

- to determine the adsorption capacity of activated alumina under continuous pilot scale operation;
- to confirm the ability of sodium hydroxide to regenerate spent activated alumina and optimize the procedure used for the regeneration process;
- to demonstrate the feasibility of lime addition to spent sodium hydroxide to remove phosphorus from the regenerant;
- to illustrate the regenerative capacity of lime treated sodium hydroxide for removal of phosphorus from activated alumina; and,
- to further define the capital and operating costs of the activated alumina adsorption process for the removal of phosphorus from chemically treated secondary effluents.

4. PILOT PLANT DESIGN AND OPERATION

4.1 Design

The Waterloo Water Pollution Control Plant was selected as the site of the pilot plant study because phosphorus removal by ferric chloride addition is currently practised on a permanent basis and a chemically pretreated secondary effluent could, therefore, be provided to the activated alumina columns. A treatment plant using ferric chloride for phosphorus removal was preferred because the presence of aluminum in effluent dosed with alum was found to interfere with determination of aluminum losses from the activated alumina columns used in the laboratory study.

In addition, the Ontario Ministry of the Environment has a pilot scale, dual media pressure filter installed at the Waterloo treatment plant for studies of the filtration properties of the final effluent. This unit was used, with minor modifications, to provide filtered final effluent as feed to the activated alumina system. Two 1,000 Igal polyethylene tanks were installed as storage reservoirs for the filter effluent, and provision for bypassing the treatment plant effluent from the filter feed tank to the activated alumina feed reservoirs was included in order that feed to the pilot plant could be maintained if problems were encountered with the filter system. A schematic of the activated alumina pilot plant showing the filter system is given in Figure 1. A photographic "flowsheet" of the system along with a brief description of the process is given in Appendix I. Details of the design and operation of the pressure filter will not be dealt with in detail in this report, except as they affected the operation of the activated alumina system.

The activated alumina system was designed to allow maximum flexibility of operation. Four five-inch diameter by six-foot high plexiglass tubes equipped with perforated flow distribution screens in the base were provided by the

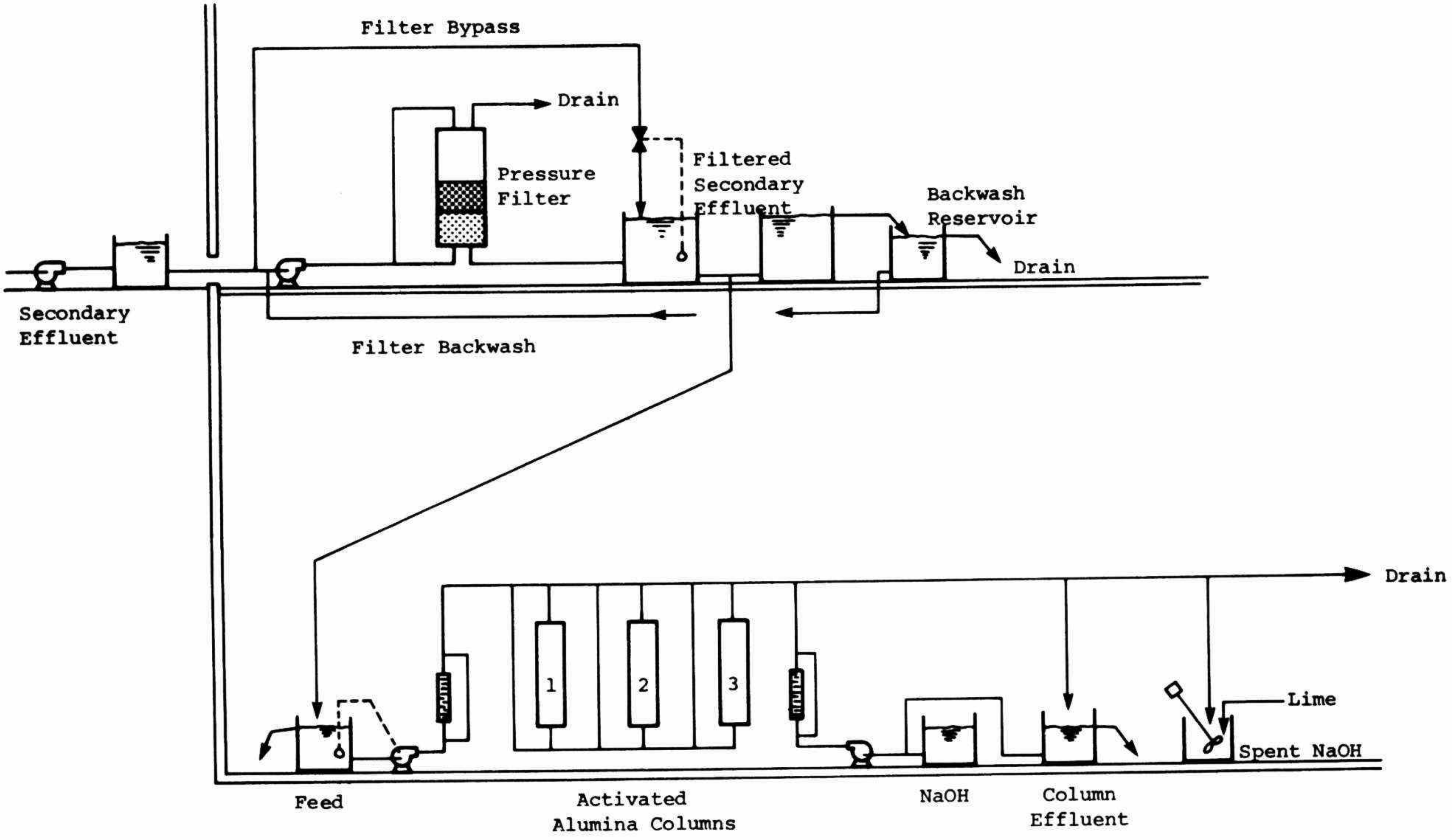

Figure 1 SCHEMATIC REPRESENTATION OF ACTIVATED ALUMINA PILOT PLANT

Ontario Ministry of the Environment for the study. Approximately six inches of pea gravel was placed in the bottom of three of the columns to provide equal flow distribution and minimize channeling during operation. To each column was added 6800 g of fresh Alcoa Fl (48-100 mesh) activated alumina to provide a bed volume of 0.32 ft^3 (2.0 Igal) in each column. To the fourth column was added a small quantity of glass wool to allow filtration of the lime treated sodium hydroxide solutions, if necessary.

The three activated alumina columns were interconnected in such a way that any two columns could be operated in series. Any single column or any two columns could also be operated in series on the filtered final effluent while the remaining column was being regenerated with sodium hydroxide. In addition, any single column could be isolated from the other two to allow separate studies on that column. Separate pumps and rotameters were provided for the feed to the column and the regenerant solution. A detailed schematic illustration of the activated alumina columns is shown in Figure 2, indicating the valving arrangement.

4.2 Operation During Saturation Cycle

For a saturation cycle on the activated alumina columns, the dual media pressure filter was operated daily to maintain filtered final effluent in the storage reservoirs. The filter was operated at relatively low surface loadings to provide a high quality feed to the activated alumina columns. The filtered feed was transferred by gravity to a 150 Igal feed tank. The flow rate from the storage reservoirs to the feed tank was maintained slightly higher than the feed rate through the alumina columns and the excess filtered effluent was discharged to drain. Thus, the feed tank could be kept full at all times. As an added precaution, a level controlled on-off switch was provided on the feed pump to prevent pump damage if the feed tank should become empty.

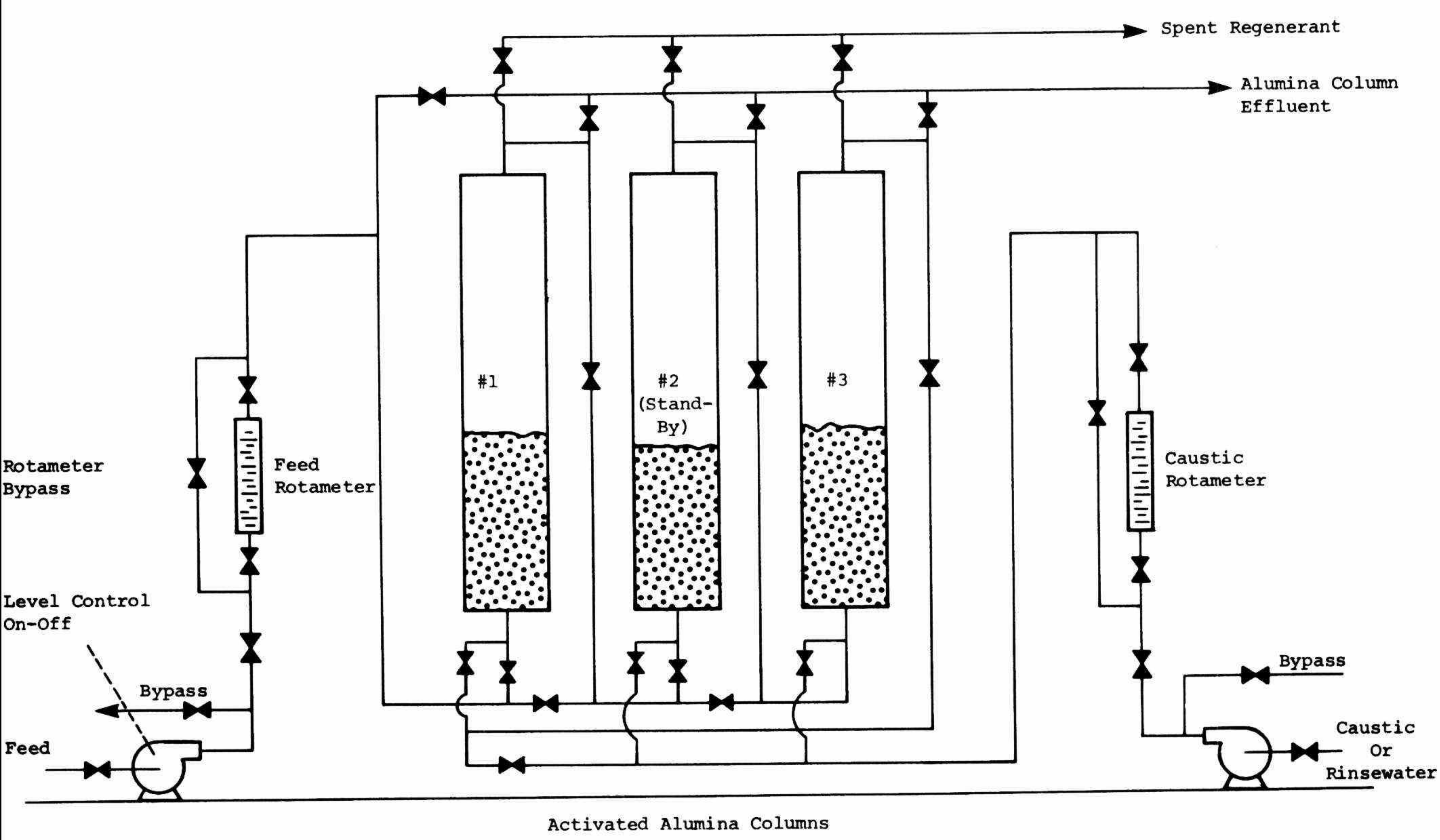

Figure 2 DETAILED SCHEMATIC ILLUSTRATION OF ACTIVATED ALUMINA COLUMN PIPING ARRANGEMENT

The activated alumina columns were operated in an upflow mode. The feed was pumped through Columns #1 and #3 in series and discharged continuously into a 150 Igal polished effluent tank provided with an overflow to drain. Samples of the feed and effluents from Column #1 and #3 were taken at regular intervals and the orthophosphorus content monitored to determine the saturation point of the individual columns. Total phosphorus analyses were done randomly on the samples for comparison with the orthophosphate results.

When the first column in series, in this case Column #1, was determined to be saturated, it was taken off line for the regeneration process. During the regeneration period, the feed flow was maintained to the other column. Following regeneration, the clean column was put back on line as the second column in series; that is, the original order of the columns was reversed and, in this specific case, the flow pattern would be from Column #3 to Column #1. A schematic representation of the activated alumina column operation during a typical saturation run is shown in Figure 3. Column #2 was designed to serve as an emergency standby throughout the study. For the final saturation runs on the pilot plant, 1700 g of fresh alumina was added to each of the operational columns. As no exhausted alumina was removed at this stage, the actual bed volume of Columns #1 and #3 increased to approximately 0.40 ft^3 (2.5 Igal).

A saturation cycle on any individual column normally involved operating that column initially as the second unit in series and then as the first unit. The saturations of the two columns therefore overlapped during the study due to the system used for operation. In reporting the results, the saturation of each individual column has been dealt with as a separate segment of operation, but the overlapping nature of the runs must be considered in analysis of the data.

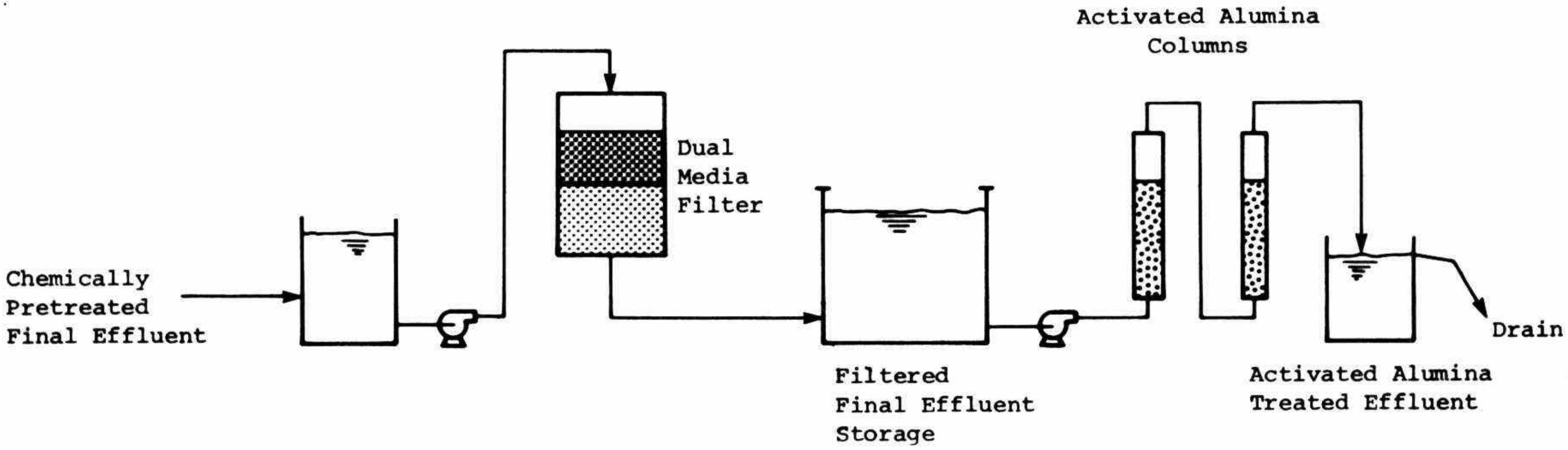
Activated Alumina Columns
Dual Media Filter
Chemically Pretreated Final Effluent
Filtered Final Effluent Storage
Drain
Activated Alumina Treated Effluent

Figure 3 SCHEMATIC REPRESENTATION OF ACTIVATED ALUMINA PILOT PLANT OPERATION DURING SATURATION RUN

4.3 Operation During Regeneration Cycle

As the objectives of the pilot scale study included optimization of the activated alumina regeneration process, the system was designed to allow wide flexibility in the modes of operation. A 150 Igal polyethylene tank was provided for makeup and feed for regeneration runs involving large volumes of sodium hydroxide solutions. Smaller polyethylene tanks of 15 Igal and 50 Igal were provided for regeneration runs involving smaller volumes of caustic.

Spent regenerant, after passing through the saturated activated alumina, could be collected in a second 150 Igal polyethylene tank or returned directly to the feed tank if the regeneration run involved recycling of the caustic solution. The piping arrangement allowed upflow regeneration of any column or series of columns independent of the flow of filtered feed to the system.

After regeneration of the column, the caustic solution could be rinsed from the clean activated alumina using column effluent or freshwater. For this study, freshwater was used to simplify the phosphorus and aluminum balance calculations. The column was rinsed at a controlled flow rate for 60 minutes or until the pH of the rinsewater was reduced to an acceptable level (pH <9). Samples of the regenerant solution and the rinsewater were taken at appropriate intervals and analyzed for total phosphorus and aluminum content in order to determine the efficiency of the regeneration cycle.

A schematic representation of the operation of the system during a typical regeneration cycle is shown in Figure 4.

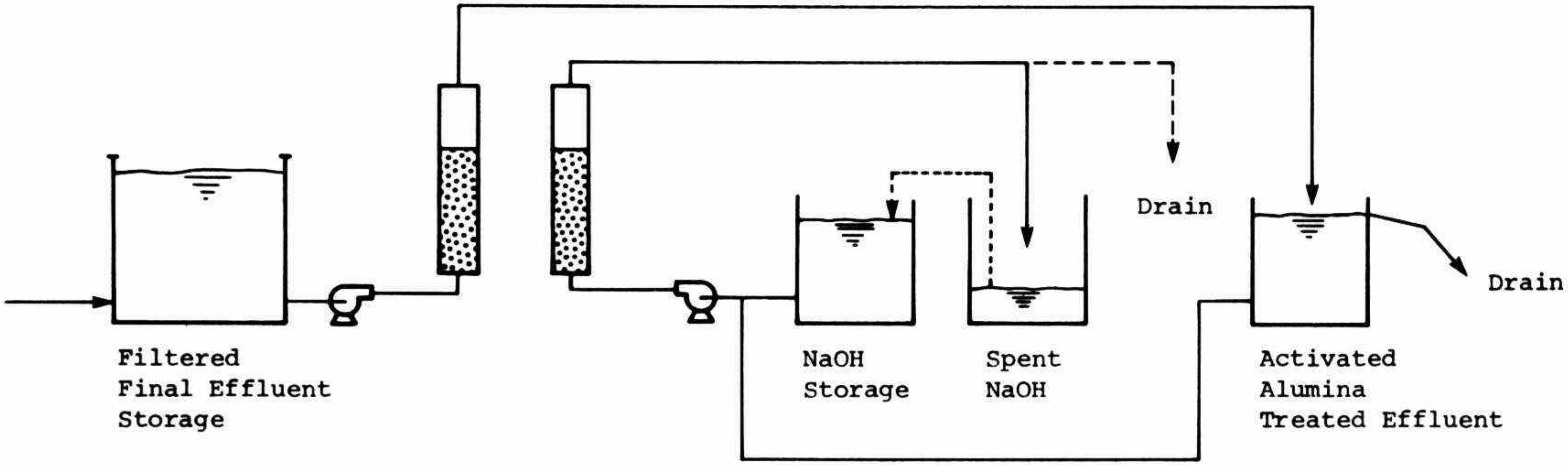

Figure 4 SCHEMATIC REPRESENTATION OF ACTIVATED ALUMINA PILOT PLANT
OPERATION OF SYSTEM DURING REGENERATION CYCLE

5. RESULTS

The three phases of the investigation, i.e. saturation, regeneration and lime precipitation, are interrelated in terms of the overall results of the study, as the efficiency of a regeneration cycle will affect the subsequent saturation cycle, and the addition of lime to the regenerant may alter the regeneration efficiency. In Section 6 of this report, these interrelated effects will be discussed in detail; however, to simplify presentation of the experimental results, the data are presented separately in this section after discussion of the operation of the system during the study. A chronological summary of the investigations is given in Table 1 to provide a guide for evaluation of the overall experimental program.

5.1 Operational Problems

In terms of fulfilling the objectives of the study, the activated alumina pilot plant functioned satisfactorily. However, some difficulties had to be overcome which resulted in deviations from the original program outline. Reference is made to the results wherever an operational change in the system may have affected the outcome of the study.

During the early stages of the pilot plant study, the ferric chloride addition system at the Waterloo treatment plant was changed from a "temporary" to a "permanent" installation. During the removal of the temporary chemical holding tank, a large volume of ferric chloride was dumped to the treatment system, resulting in extremely low phosphorus concentrations in the final effluent for an extended period. Chemical addition did not recommence until the permanent facilities were completed and the phosphorus content of the secondary effluent progressively increased to over 3 mg/l.

After phosphorus removal was reimplemented, problems were encountered in controlling the chemical dosage to maintain a residual phosphorus concentration of approximately 1 mg/l.

TABLE 1. SUMMARY OF ACTIVATED ALUMINA STUDY

Chronological Order of Events

DATE	EVENT
Oct. 7 - Oct. 18	Saturation - Column #1 - First
Oct. 18	Regeneration 1 - Column #1
Oct. 7 - Oct. 23	Saturation - Column #3 - First
Oct. 18 - Oct. 23	Saturation - Column #1 - Second
Oct. 23	Regeneration 2 - Columns #1&#3
Oct. 23 - Oct. 29	Saturation - Column #1 - Third
Oct. 23 - Oct. 29	Saturation - Column #3 - Second
Oct. 29	Regeneration 3 - Columns #1&#3
Oct. 29 - Nov. 5	Saturation - Column #1 - Fourth
Nov. 5	Regeneration 4 - Column #1
Nov. 29 - Nov. 8	Saturation - Column #3 - Third
Nov. 8	Regeneration 5 - Column #3
Nov. 5 - Nov. 29	Saturation - Column #1 - Fifth
Nov. 29	Regeneration 6 - Column #1
Nov. 8 - Dec. 4	Saturation - Column #3 - Fourth
Dec. 4	Lime Precipitation - Run 1
Dec. 4	Regeneration 7 - Column #3
Nov. 29 - Dec. 13	Saturation - Column #1 - Sixth
Dec. 13	Lime Precipitation - Run 2
Dec. 13	Regeneration 8 - Column #1
Dec. 4 - Dec. 24	Saturation - Column #3 - Fifth
Dec. 24	Regeneration 9 - Column #3
Dec. 13 - Dec. 28	Saturation - Column #1 - Seventh
Dec. 28	Lime Precipitation - Run 3
Dec. 28	Regeneration 10 - Column #1
Jan. 7	Lime Precipitation - Run 4
Dec. 24 - Jan. 9	Saturation - Column #3 - Sixth
Dec. 28 - Jan. 9	Saturation - Column #1 - Eighth
Jan. 9	Regeneration 11 - Columns #1&#3
Jan. 9 - Jan. 24	Saturation - Column #1 - Ninth
Jan. 24	Regeneration 12 - Column #1

TABLE 1 (CONT'D)

DATE	EVENT
Jan. 9 - Jan. 31	Saturation - Column #3 - Seventh
Jan. 24 - Jan. 31	Saturation - Column #1 - Tenth
Jan. 31	Regeneration 13 - Columns #1&#3

Wide variations in the phosphorus content of the pilot plant feed were noted for the duration of the study. These fluctuations in the feed quality made it extremely difficult to estimate the expected duration of a saturation cycle.

Following installation of the permanent ferric chloride facilities, half of the biological capacity of the treatment plant was shut down for maintenance on the aeration equipment. In order to dewater the aeration tanks, the final effluent pump was removed from the effluent channel, cutting off the feed to the filter. This resulted in a shutdown of the pilot plant which lasted for approximately a week until a replacement pump could be installed. The maintenance program continued for about three weeks and during this period, the quality of the filter feed, in terms of suspended solids concentration, was extremely variable and resulted in some problems with the operation of the filter.

In addition, problems were encountered with the pump handling the overflow from the activated alumina system. Several short shutdowns were required while this pump was repaired. However, this did not appear to significantly affect the results of the study.

The dual media pressure filter operated without difficulty when the solids content of the feed was maintained at a reasonable level. No shutdowns of this system were required and the emergency filter bypass was never used. A high quality activated alumina column feed containing less than 5 mg/l suspended solids was provided by the filter. However, the filter passed a small quantity of colloidal material which analysis indicated to be ferric phosphate floc. This material was not removed to any significant degree in the activated alumina beds and consequently difficulties were encountered in attaining polished effluent phosphorus concentrations of less than 0.10 mg/l.

Despite the relatively low suspended solids concentrations in the column feed, solid accumulation in the feed rotameter and the pea gravel was noted after several thousand bed volumes had been passed through the system. The rotameter had to be taken off line eventually and used only for periodic checks on the feed rate. The solids in the base of the column caused some channeling through the activated alumina beds.

The size of the Alcoa F1 activated alumina (approximately 0.15 - 0.30 mm) also created some operational difficulties during the study. In the standby column (Column #2), the alumina settled through the pea gravel base and the distribution screen and into the inlet piping, resulting in plugging of the inlet ball valve. This problem was compounded by the presence of solids and ogranics collected in the bottom of the operational columns. During the period when the system was shut down for maintenance on the aeration tanks, the alumina in Columns #1 and #3 settled into the piping and hardened in the base of the columns. On start-up, no flow could be forced through the system and the columns had to be dismantled and cleaned before operation could be resumed.

The wide fluctuations in feed phosphorus concentration hampered smooth operation of the system to the defined saturation level of 0.5 mg/l phosphorus in the effluent. During prolonged periods of high phosphorus loading, "breakthrough" of the activated alumina occurred too rapidly to allow adequate time for analytical feedback on the operation of the system. As a result, some saturation cycles were continued to high effluent phosphorus concentrations and, in many cases, both columns were virtually saturated simultaneously. During prolonged periods of feed phosphorus concentrations of less than 0.5 mg/l, the defined "breakthrough" point could never be attained. In addition, the presence of a small fraction of apparently nonadsorbable phosphorus made the definition of "breakthrough" based on a ratio of effluent to feed (C/Co) phosphorus impossible.

During the early stages of the study, the feed rate was maintained at 0.9 Igal/min (4.1 l/min), which resulted in approximately 80 percent expansion of the bed. Nominal residence time at this feed rate, based on the packed bed volume of 2 Igal, was 2.2 minutes. However, due to the high phosphorus loading and resultant rapid saturation of the alumina, the feed rate was reduced to 0.6 Igal/min (2.7 l/min; nominal residence time = 3.3 min), and ultimately to 0.5 Igal/min (2.3 l/min; nominal residence time = 4 min). Column expansion at the lower flow rate was approximately 50 percent. Any effect of increased contact time on the operation of the system appeared to be masked by the high degree of fluctuation in the feed quality.

Despite the wide variation in regeneration methods investigated, the operational problems during this phase of the study were minimal. The sodium hydroxide solution did have a tendency to foam during pumping and this resulted in some carryover of alumina, especially when small volumes of regenerant solution were used. This carryover is indicated as an alumina loss from the system.

A high degree of dilution of the regenerant solution was also noted when small volumes of caustic were used, due to the volume of liquid present in the column at the start of the regeneration cycle. Therefore, to minimize the dilution effect, the columns were allowed to settle and the liquid in the column was decanted before and after the regenerations.

5.2 Saturation of Activated Alumina Columns

The performance of the activated alumina columns was evaluated based on feed and effluent orthophosphate analyses. However, to ensure that this analytical procedure would provide adequate information regarding the operation of the system, random samples were analyzed for total phosphorus. The results, as summarized in Table 2, indicate that approximately 90 percent of the phosphorus in the column feed was in orthophosphate

TABLE 2 COMPARISON OF TOTAL PHOSPHORUS AND ORTHOPHOSPHATE ANALYSES OF ACTIVATED ALUMINA COLUMN FEED AND EFFLUENT SAMPLES

Column Feed		Column Effluents			
Total Phosphorus (mg/l)	Orthophosphate (as P) (mg/l)	Total Phosphorus (mg/l)		Orthophosphate (as P, mg/l)	
		Col. 1	Col. 3	Col. 1	Col. 3
0.34	0.30	0.09	0.11	0.08	0.11
0.52	0.43	0.09	0.11	0.08	0.12
0.74	0.67	0.47	0.21	0.41	0.13
1.17	0.95	0.32	0.28	0.29	0.23
0.74	0.75	0.34	0.23	0.25	0.19
1.26	1.20	0.38	0.89	0.33	0.82
0.99	0.88	0.33	0.70	0.30	0.66
0.57	0.48	0.26	0.29	0.15	0.21
0.55	0.44	0.28	0.18	0.22	0.11
0.10	0.01	0.22	0.11	0.15	0.04
0.25	0.20	0.30	0.18	0.25	0.15
1.90	1.74	0.79	0.22	0.78	0.20
1.72	1.50	0.32	0.14	0.26	0.12
1.84	1.62	0.32	0.38	0.24	0.29
Avg. 0.906	0.798	0.322	0.288	0.271	0.241

form, and that only about 50 percent of the feed phosphorus not included in the orthophosphate analyses is adsorbed by the activated alumina. The rapid analytical feedback provided by the orthophosphate test was felt to justify the small error resulting from its use.

Details and analytical results of the saturation cycles are summarized in chronological order of the date of saturation in Appendix II. These summaries also indicate the position of the pertinent column in the series. From this information, the quality of the activated alumina column feed and final polished effluent can be extracted.

The quantities of orthophosphate fed to the column during each saturation cycle and the amount of orthophosphate adsorbed by the activated alumina were determined by numerical integration of the feed and effluent orthophosphate data and the volume of feed which was passed through the column during the run. A typical concentration-volume curve is shown in Figure 5.

During the study, Column #1 underwent ten saturation cycles while Column #3 was saturated only seven times. This discrepancy was caused by four regeneration cycles which involved both columns simultaneously. After each of these regenerations, Column #1 was placed as the first column in series and, therefore, became saturated before Column #3.

5.3 Regeneration of Activated Alumina Columns

Data regarding the regeneration techniques investigated during the course of the study are summarized chronologically in Appendix III. These summaries indicate the column which was regenerated along with the method used for the regeneration. Analytical results of regenerant samples and rinsewater samples are also given in the summaries in tabular form. From these results, the efficiency of the regenerant technique in terms of percent recovery of the phosphorus adsorbed during the previous saturation cycle, the activated

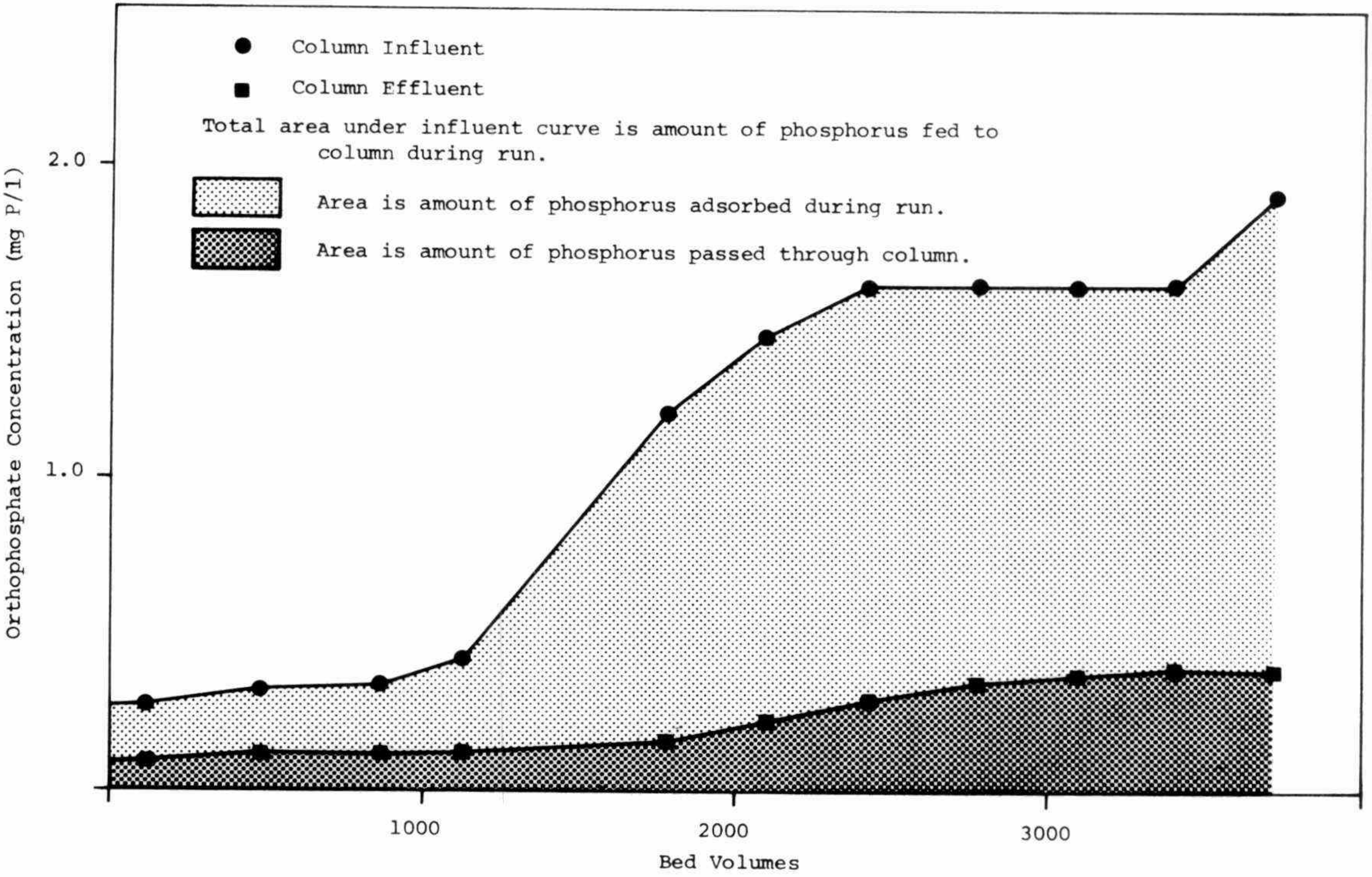

Figure 5 TYPICAL ORTHOPHOSPHATE CONCENTRATION - VOLUME CURVE FOR ACTIVATED ALUMINA SATURATION CYCLE

Data From Saturation 2, Column 3

alumina lost in the regenerant and the rinsewater, as well as sodium hydroxide losses during the process, were determined. These calculations are included in the summary sheets.

The objective of the regeneration phase of the study was to optimize the phosphorus removal from the spent activated alumina and to minimize the activated alumina losses. Various methods were investigated with varying degrees of success. As the condition of the activated alumina after the regeneration has a significant effect on the subsequent saturation runs, the actual weight of alumina remaining in the column and the residual phosphorus content is also stated in the regeneration summaries. The effect of this regeneration optimization on the study results will be discussed in more detail in Section 6.

The investigation involved three basic modes of regeneration:

- recirculation of a large volume of sodium hydroxide solution through the spent activated alumina;
- recirculation of a small volume of sodium hydroxide solution for an equivalent time through the spent alumina; and,
- once through elution of the activated alumina with sodium hydroxide.

In addition, the effect of regenerant strength was evaluated during the study.

5.4 Lime Precipitation of Phosphorus from Regenerant Solutions

Samples of used regenerant were returned for laboratory jar testing to determine the required dosages and conditions for phosphorus removal from these solutions. The results of these laboratory studies are summarized in Table 3. The range of phosphorus removal attained during each run for the dosages and contact times investigated are shown graphically in Figure 6.

TABLE 3 LIME PRECIPITATION OF PHOSPHORUS FROM SPENT CAUSTIC REGENERANT SOLUTIONS - LABORATORY RESULTS

$Ca(OH)_2$ Dosage (g/l)	Stirring Time (hours)	Total Phosphorus Concentration (mg/l)		Phosphorus Removal (percent)	
		Run 1	Run 2	Run 1	Run 2
0	0	250.0	70.1	-	-
2	1	21.5	14.3	91.4	79.6
2	2	-	-	-	-
2	3	-	-	-	-
2	4	11.3	11.9	95.5	83.0
4	1	8.6	7.0	96.6	90.0
4	2	4.8	5.6	98.1	92.0
4	3	4.0	4.6	98.4	93.4
4	4	3.6	4.4	98.6	93.7
8	1	2.9	4.4	98.8	93.7
8	2	2.1	3.4	99.2	95.1
8	3	1.8	3.1	99.3	95.6
8	4	1.6	1.8	99.4	97.4

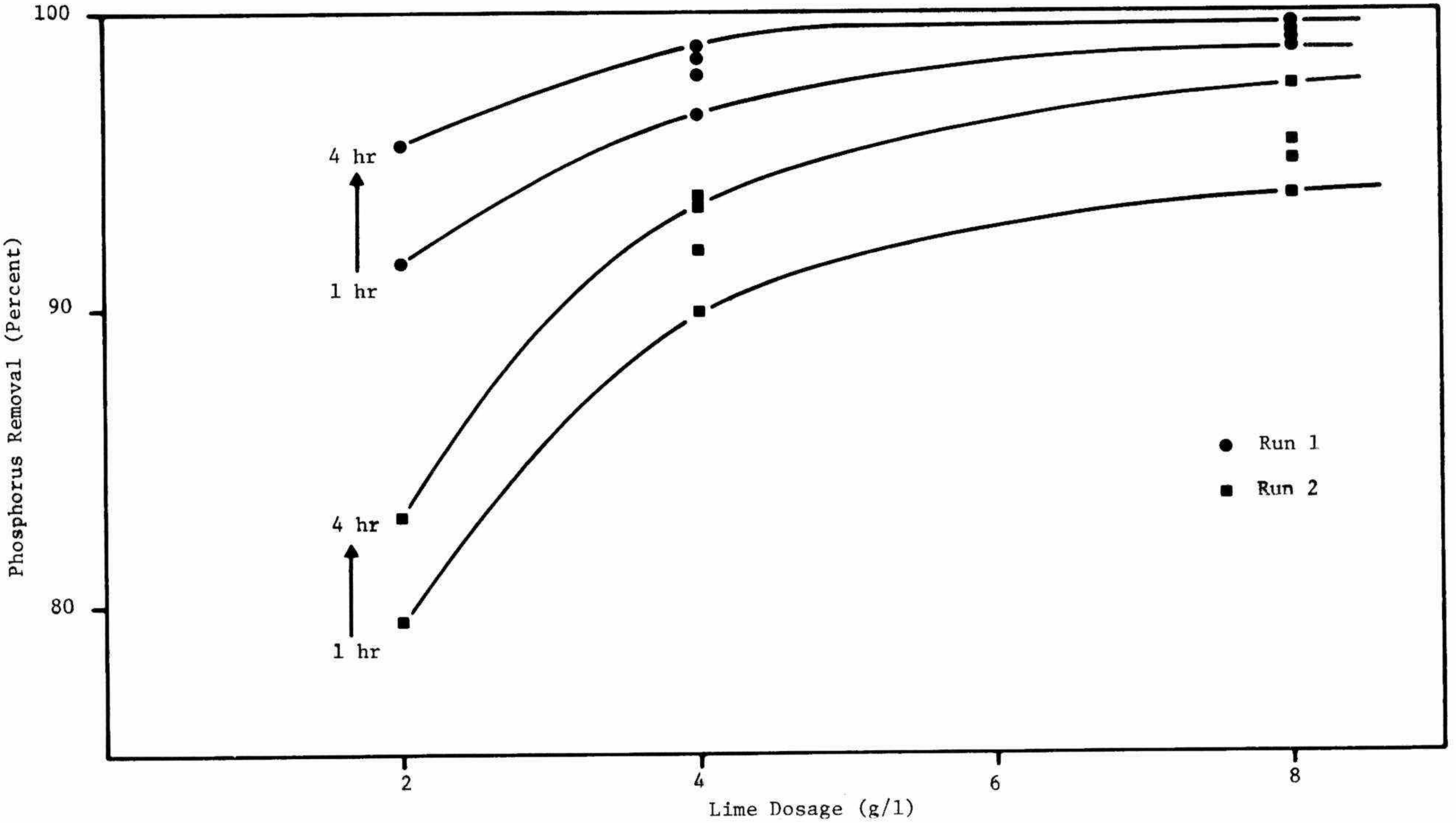

Figure 6 LIME PRECIPITATION OF PHOSPHORUS FROM SPENT CAUSTIC SOLUTION - LABORATORY RESULTS

After optimization of the process in the laboratory, the technique was used on spent regenerant solutions in the field. The results of the four lime precipitations carried out in the field are given in Table 4.

These lime treated caustic solutions were subsequently used for Regenerations 7, 8, 9, and 10, as noted in the regeneration summaries in Appendix II, in order to evaluate the effect of lime on the performance of the regenerant and the activated alumina.

TABLE 4 LIME PRECIPITATION OF PHOSPHORUS FROM SPENT CAUSTIC REGENERANT SOLUTIONS - PILOT PLANT RESULTS

Run #	Date	Initial Phosphorus Content (mg/l)	$Ca(OH)_2$ Dosage (g/l)	Stirring Time (hours)	Final Phosphorus Content (mg/l)	Phosphorus Removal Efficiency (percent)	Sludge Production (Volume percent)
1	Dec. 4	190.0	8	2	91.5	52.5	5.5
2	Dec. 13	117.5	8	4	13.7	88.5	4.1
3	Dec. 28	115.0	8	4	3.1	97.4	2.0
4	Jan. 7	70.0	8	4	6.3	91.0	67.0

6. DISCUSSION OF RESULTS AND PROCESS IMPLICATIONS

The results presented in the previous section indicate that the adsorption of residual phosphorus from chemically pretreated secondary effluents is technically feasible. The orthophosphate concentration of the final effluent from the activated alumina columns is shown in Figure 7 for the duration of the pilot plant study. The average quality of the system effluent was 0.25 mg P/l; however, as indicated in Figure 7, this includes data from two cycles in which the effluent from the final activated alumina column exceeded 1.00 mg P/l due to the aforementioned operational problems. The performance of the activated alumina system can be readily restored following regeneration with sodium hydroxide, even if the columns are run until the effluent reaches high phosphorus concentrations.

The quality of the polished effluent depends on the operational procedures. However, the results of this study indicate that, using the filtered secondary effluent from the Waterloo Water Pollution Control Plant, the minimum polished effluent orthophosphate concentration is approximately 0.10 mg P/l, due to the small residual fraction of the feed phosphorus which cannot be removed in the activated alumina columns, regardless of their condition. This nonremovable fraction was not noted in the laboratory studies using alum treated Oakville secondary effluent and, therefore, may be a characteristic which varies at different treatment plants.

The wide fluctuations in the feed orthophosphate concentration had the greatest effect on the performance of the activated alumina system. The average quality was 1.07 mg P/l; however, the feed concentration varied from about 0.1 mg P/l to more than 3.0 mg P/l and the variations occurred very rapidly. These changes in feed quality made control of the column operation extremely difficult.

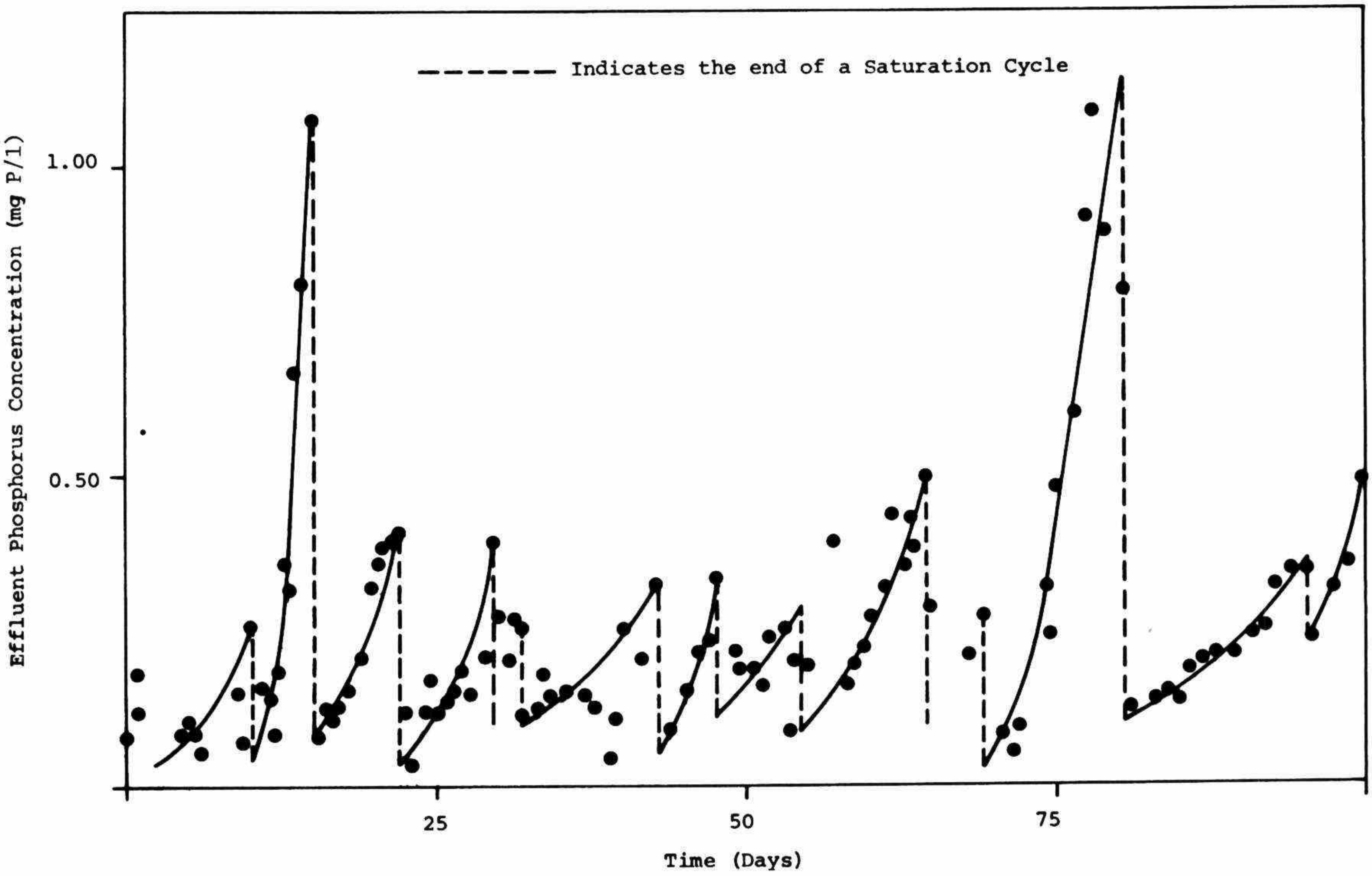

Figure 7 ORTHOPHOSPHATE CONCENTRATION IN ACTIVATED ALUMINA COLUMN FINAL EFFLUENT

6.1 Discussion of Saturation Cycles

The capacity of the activated alumina for adsorption of phosphorus is a major factor in establishing the process feasibility. In order to maintain a consistent basis for comparison of the capacity between cycles, a "saturation" or "breakthrough" point must be defined; however, as mentioned previously, the rapidity and magnitude of the feed quality variations, the residual nonadsorbable phosphorus and the variations in regeneration techniques combined to make definition of this endpoint very difficult. Therefore, the capacity data must be compared objectively within the framework of the conditions at the time of the run.

A typical adsorption breakthrough curve is given in Figure 8, based on the data obtained from the third saturation of Column #1. The feed orthophosphate content was maintained relatively constant throughout this run and sufficiently high to negate the effect of the residual phosphorus content of the effluent. This breakthrough curve is comparable to the results obtained in the laboratory study, except that the saturation time is short because of the high phosphorus loading.

The saturation data for Columns #1 and #3 are summarized in Tables 5 and 6, respectively. The capacity of the columns, in terms of the weight in milligrams of phosphorus adsorbed per gram of activated alumina in the column, is presented in Table 7. Three different capacities are calculated for each cycle:

- capacity based on the weight of phosphorus adsorbed during that cycle per gram of activated alumina present in the column at the start of the study;
- capacity based on the weight of phosphorus adsorbed during that cycle per gram of activated alumina present in the column during that cycle; and,

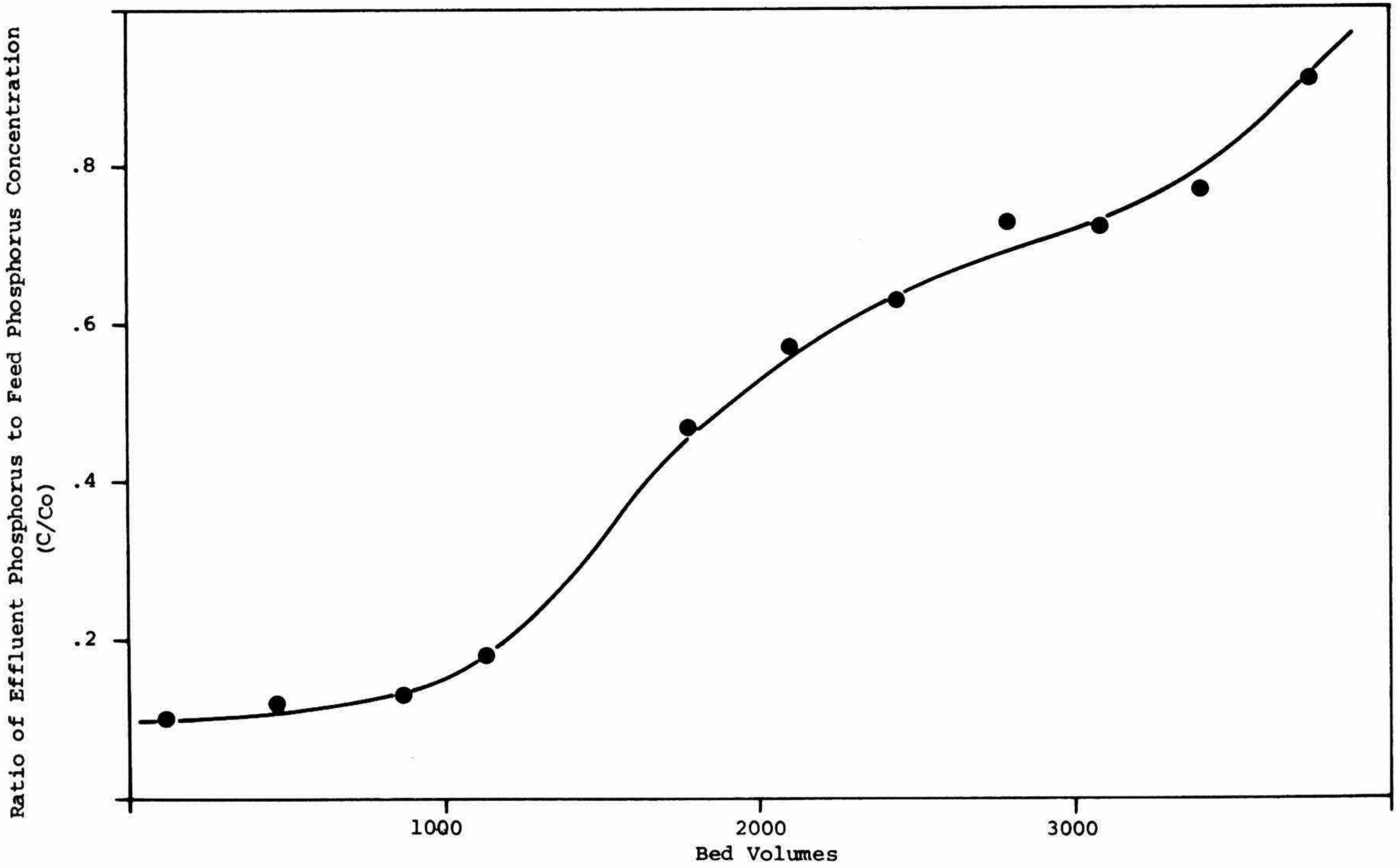

Figure 8 TYPICAL ORTHOPHOSPHATE BREAKTHROUGH CURVE

Column 1, Saturation Cycle 3

Average Feed Concentration = 2.21 mgP/l

TABLE 5

SUMMARY OF COLUMN 1 SATURATION CYCLES

Saturation Number	Activated Alumina In Column (grams)	Orthophosphate Fed to Column (grams P)	Orthophosphate Adsorbed (grams P)	Residual Phosphorus From Previous Cycles (grams P)	Total Phosphorus On Activated Alumina (grams P)
1	6,800	48.00	32.44	0.00	32.44
2	6,500	32.52	22.87	9.19	32.06
3	6,360	82.32	46.18	11.73	57.91
4	6,335	24.59	16.11	40.07	56.18
5	6,320	24.79	11.86	28.71	40.57
6	6,280	21.01	10.67	26.74	37.41
7	6,270	27.96	12.47	32.21	44.68
8	6,265	30.61	14.34	36.92	51.26
9	7,940	36.07	17.68	42.29	59.97
10	7,740	19.42	11.57	41.31	52.88

TABLE 6 SUMMARY OF COLUMN 3 SATURATION CYCLES

Saturation Number	Activated Alumina In Column (grams)	Orthophosphate Fed to Column (grams P)	Orthophosphate Adsorbed (grams P)	Residual Phosphorus From Previous Cycles (grams P)	Total Phosphorus On Activated Alumina (grams P)
1	6,800	75.97	31.90	0.00	31.90
2	6,660	36.63	29.15	11.71	40.86
3	6,635	22.69	12.14	28.28	40.24
4	6,580	26.89	12.63	35.53	48.16
5	6,560	39.11	15.92	38.34	54.26
6	6,550	48.94	19.01	47.64	66.65
7	8,225	44.28	15.87	54.99	70.86

TABLE 7 CAPACITY OF ACTIVATED ALUMINA FOR ADSORPTION OF PHORPHORUS

Column 1:

Saturation Cycle Number	Activated Alumina Capacity (mg P/g Al_2O_3) Based on Initial Al_2O_3 Weight and Phosphorus Adsorbed during Cycle	Based on Actual Al_2O_3 Weight and Phosphorus Adsorbed during Cycle	Based on Actual Al_2O_3 Weight and Total Phosphorus on Column
1	4.77	4.77	4.77
2	3.36	3.52	4.93
3	6.79	7.26	9.11
4	2.37	2.54	8.87
5	1.74	1.88	6.42
6	1.57	1.70	5.96
7	1.83	1.99	7.13
8	2.11	2.29	8.18
9	2.08*	2.23	7.55
10	1.36*	1.49	6.83

Column 2:

Saturation Cycle Number	Activated Alumina Capacity (mg P/g Al_2O_3) Based On Initial Al_2O_3 Weight and Phosphorus Adsorbed during Cycle	Based on Actual Al_2O_3 Weight and Phosphorus Adsorbed during Cycle	Based on Actual Al_2O_3 Weight and Total Phosphorus on Column
1	4.69	4.69	4.69
2	4.29	4.42	6.19
3	1.79	1.83	6.06
4	1.86	1.92	7.32
5	2.34	2.43	8.27
6	2.90	2.90	10.18
7	1.87*	1.93	8.62

*Based on 6,800 g Initial Al_2O_3 plus 1,700 g Make-up (8,500 g Al_2O_3)

- capacity based on the total weight of phosphorus on the column at the end of the cycle (i.e. phosphorus adsorbed during that cycle and residual phosphorus from previous cycles) per gram of activated alumina present in the column.

From these data, the total reduction in adsorption capacity of the alumina can be determined, as well as the fraction of this reduction which is due directly to losses of activated alumina during regeneration. In addition, the third calculation allows the estimation of the fraction of activated alumina which can be reused.

The initial capacity of the activated alumina was found to be approximately 4.75 mg P/g Al_2O_3 on both columns. This is somewhat lower than the capacity determined in the laboratory study, although it is difficult to compare the results because of the different experimental conditions.

In the case of Column #1, the capacity of the activated alumina dropped during the second cycle and increased again during the third cycle. However, in the second cycle, the column was regenerated before it had reached an adequate degree of saturation and, in the third cycle, it was maintained on line for a much longer period. The results for Column #3 show that the capacity remained approximately constant in the second saturation cycle. The capacity during the third cycle was extremely low but this was due to an extremely short run of that column.

After the third saturation cycle, the capacity of the activated alumina was significantly reduced. On Column #1, the capacity based on the initial activated alumina weight dropped to 2.4 mg P/g Al_2O_3 during the sixth cycle. Only a small portion of this reduction is due to inadequate removal of phosphorus from the alumina; the majority of the capacity loss could be caused by fouling of the alumina surface by organics and other material in the feed, as well as loss of adsorptive surface area resulting from the regeneration process.

A similar trend is evident from the results for Column #3. The capacity of the alumina during the fourth cycle was 1.9 mg P/g Al_2O_3. The previous regeneration had removed only 40 percent of the phosphorus present, which probably contributed to the more rapid reduction in adsorptive capacity for Column #3. Prior to the seventh and eighth saturation cycles on Column #1 and the fifth and sixth cycles on Column #3, the columns were regenerated with caustic solutions containing lime as a result of the phosphorus precipitation process. In all cases, the capacity during the subsequent cycle increased slightly despite relatively low phosphorus recovery for three of the four regenerations. This phenomenon of apparent increase in phosphorus adsorptive capacity due to the presence of calcium in the column has been noted in the literature and is probably due to chemical reaction of the calcium entrapped in the alumina with the feed phosphorus. It has also been reported that this reaction leads to an ultimate decrease in the overall capacity, as the alumina becomes fouled with the calcium phosphate. The extent of this study was not sufficient to fully evaluate these findings.

During the last saturation cycles, fresh activated alumina (1,700 g) was added to each of the columns. This resulted in no significant increase in the column capacity; in fact, the capacity was reduced in Column #3. It is possible that the addition of fresh alumina to the bed merely compensated for the further decrease in capacity of the original media.

The phosphorus capacity based on the actual weight of activated alumina in the column indicates that only a small fraction of the capacity reduction is due to losses of activated alumina during regeneration. Therefore, in order to maintain the performance of the system, it will be necessary to remove spent alumina from the columns and add fresh makeup alumina as the total capacity reduction occurs much more rapidly than the reduction in the column bed volume.

The phosphorus capacity of the activated alumina based on the total weight of phosphorus present on the bed indicates that the alumina is capable of adsorbing as much as 10 mg P/g Al_2O_3 if the phosphorus is allowed to diffuse into the particles. However, only a portion of this total capacity is reusable and, therefore, significant for any process application.

The activated alumina capacity based on the weight of fresh Al_2O_3 added to the column is shown in Figure 9 for the duration of the study. These data must, of course, be considered with regard to the other conditions affecting the operation of the column as discussed previously.

6.2 Discussion of Regeneration Results

The regeneration results are summarized in Table 8, showing the phosphorus recovery efficiency, as well as the losses of activated alumina and sodium hydroxide. The aluminum losses are low except during the first regeneration of fresh alumina. The average value during regenerations of 17 saturated columns was only 1.06 percent; however, for the regenerations involving columns containing no fresh alumina, the average loss was only 0.35 percent.

The data indicate that a small volume of regenerant (5 bed volumes) recirculated seven times results in higher aluminum losses (0.85%, 0.67%) than regeneration with a large volume of sodium hydroxide solution. Further, the addition of lime to the caustic for phosphorus precipitation appears to reduce the aluminum losses. The losses following each of three successive lime treatments progressively decreased (0.32%, 0.15% (avg.) and 0.09%) for regenerant solutions treated once, twice, and three times with lime.

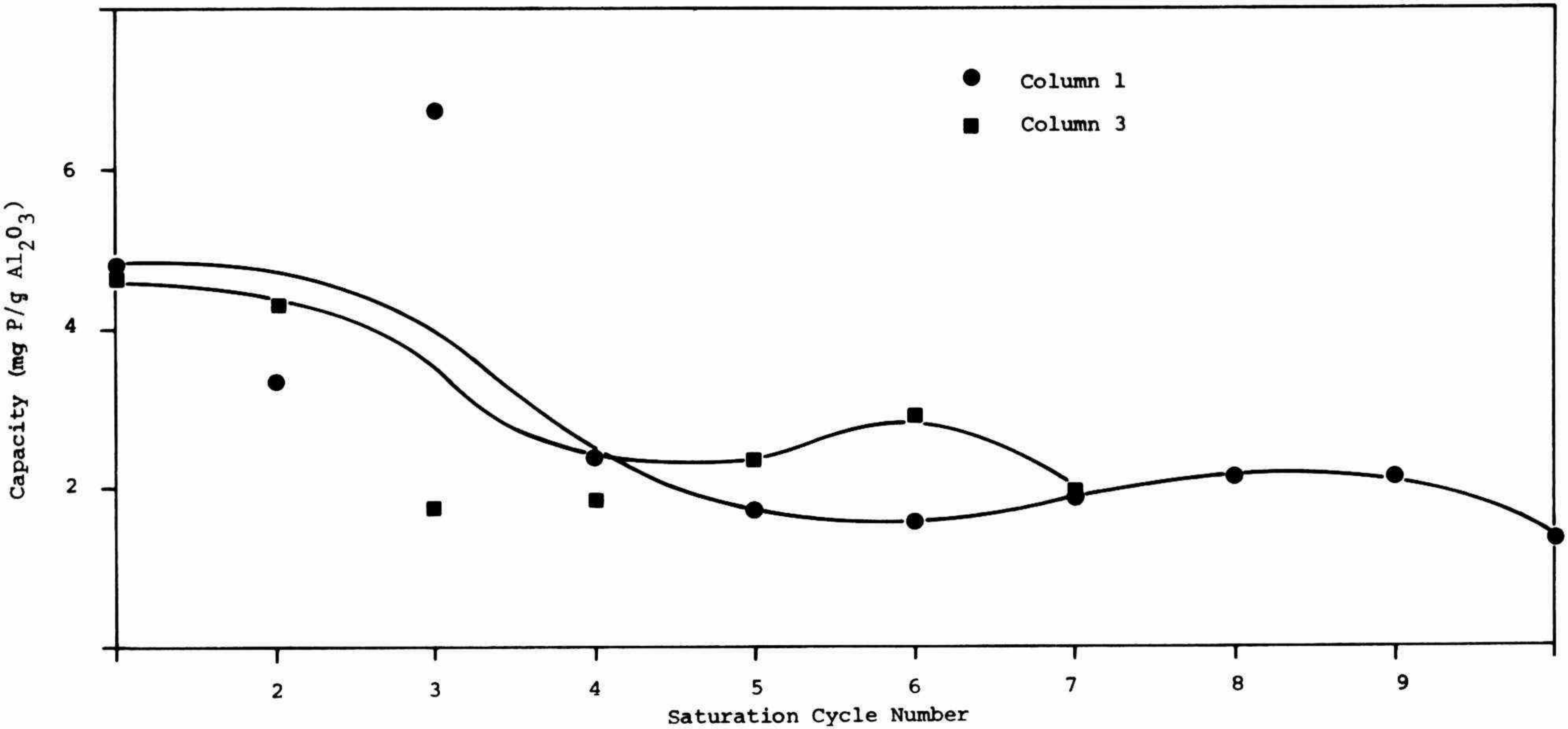

Figure 9 EFFECT OF SATURATION CYCLES ON ACTIVATED ALUMINA CAPACITY (Based on Initial Al_2O_3 and Phosphorus Adsorbed During Cycle)

TABLE 8 SUMMARY OF ACTIVATED ALUMINA REGENERATION DATA

Regeneration Number	Regeneration Efficiency (Adsorbed Phosphorus Recovery, %)	Activated Alumina Loss		Regenerant Loss	
		g Al_2O_3	Percent	g NaOH	Percent
1	71.7	161.2	4.5	1,816	5.9
2*	74.0	285.7	2.2	3,087	10.6
3*	40.4	49.1	0.37	2,905	11.5
4	170.8	12.5	0.20	1,090	4.9
5	40.3	29.9	0.85	582	33.0
6	82.5	42.2	0.67	908	25.4
7	77.8	21.2	0.32	1,090	7.0
8	48.7	11.2	0.18	291	7.6
9	41.6	7.1	0.11	290	8.2
10	62.2	5.4	0.09	182	5.6
11*	61.9	47.4	0.37	1,453	8.7
12	105.5	217.4	2.7	1,453	10.0
13*	116.5	187.3	1.2	817	7.1
Average	-	82.9	1.06	1,228	-

*Two saturated Activated Alumina columns regenerated simultaneously.

The sodium hydroxide losses during regeneration are a result of the displacement of the liquid contents of the system into the regenerant solution at the start of the process, and the loss of the equivalent volume of regenerant to the drain when the rinsewater cycle is started. The losses can be minimized by draining as much of the liquid from the system as possible before and after regeneration. Even with these precautions, however, the percentage loss of sodium hydroxide during the process is high when using small volumes of regenerant solution.

The efficiency in terms of the percentage of the adsorbed phosphorus removed from the alumina shows wide variation even for the same mode of regeneration. The recovery is affected by the degree of saturation of the column and the time that the adsorbed phosphorus has to diffuse into the alumina particles, as well as the strength and volume of the regenerant solution.

A large volume of regenerant recirculated for the equivalent of 35 bed volumes per column provides a high degree of phosphorus recovery (83% average for regeneration of eight columns) and relatively low aluminum losses. The results also show that the regeneration is effective even if the same caustic solution is used several times. Continued phosphorus removal was found to be possible with caustic containing over 150 mg/l phosphorus.

Regeneration of the spent activated alumina columns by recirculation of a small volume of caustic (5 B.V.) for an equivalent total regenerant alumina contact period showed contradictory results. Regeneration 5 using 1N NaOH gave very low phosphorus recovery (40.3%) and relatively high aluminum losses after being recirculated seven times. The effect of recirculation time on the phosphorus elution, as shown in Figure 10, indicates that a high recovery (80%) was attained after approximately the first two recirculations. Continued contact with the regenerant resulted in readsorption of the

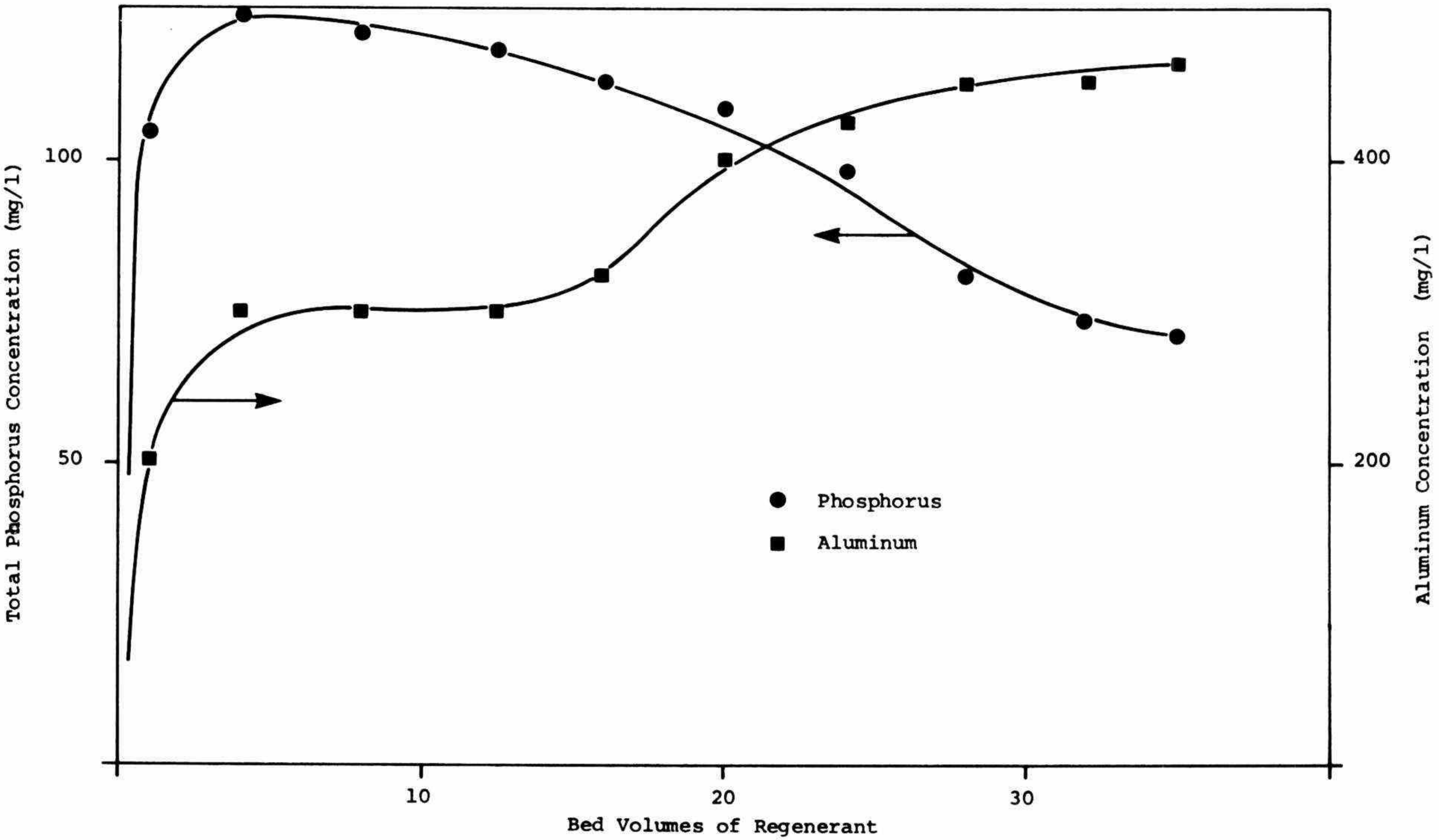

Figure 10 EFFECT OF RECIRCULATION OF 1 N NaOH REGENERANT SOLUTION

Volume of Regenerant = 5 Bed Volumes
Data From Regeneration Number 5

phosphorus onto the activated alumina. Regeneration 6 using the same procedure with 2N NaOH resulted in a much higher ultimate phosphorus recovery (82.5%). The results are shown in Figure 11 and confirm that the majority of the phosphorus is recovered during the initial phase of the process. There was no readsorption of the recovered phosphorus when 2N NaOH was used. It appears that there is a minimal NaOH requirement to provide adequate removal of the phosphorus from the alumina bed.

Regeneration of the spent activated alumina by passing 1N or 2N NaOH once through the column appeared to provide the best regeneration in terms of phosphorus recovery. In Regeneration 13, using 2N NaOH, all of the phosphorus which was ultimately removed from the column was recovered in the initial nine bed volumes of caustic solution. Similar results were obtained in Regeneration 12 with 1N NaOH, although the sampling was not sufficient to precisely define the minimum regenerant requirement. In Regeneration 8, using a lime treated caustic solution, the same pattern was evident. The results are shown in Table 9 for Regenerations 8 and 12 to indicate the incremental amount of phosphorus recovered from the saturated activated alumina by continued contact of the alumina with the regenerant.

Addition of lime to the caustic solutions for removal of phosphorus did not significantly reduce the phosphorus recovery from the activated alumina when large volumes of caustic were used (Regeneration 7; 77.8 percent recovery). However, the use of caustic which had been treated two or three times with lime, using the once through regeneration mode, did result in lower removal efficiencies (Regenerations 7, 8, 9; average recovery, 50 percent). Further studies would be required to define more precisely the effect of lime addition on the phosphorus recovery capabilities of the regenerant.

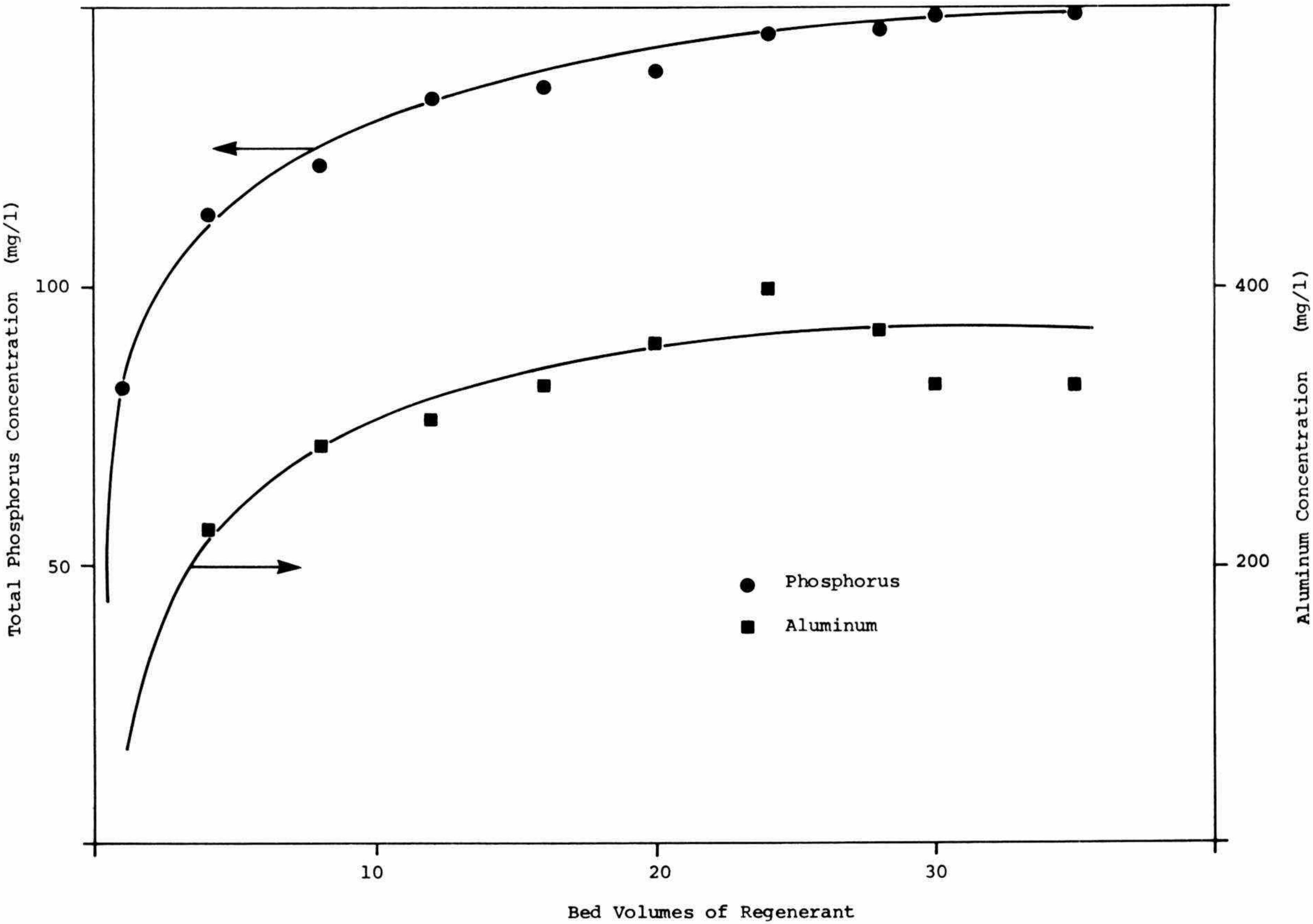

Figure 11 EFFECT OF RECIRCULATION OF 2N NaOH REGENERANT SOLUTION

Volume of Regenerant = 5 Bed Volumes
Data From Regeneration Number 6

TABLE 9

DETERMINATION OF REGENERANT VOLUME REQUIRED FOR ONCE THROUGH REGENERATION OF SPENT ACTIVATED ALUMINA

Regeneration Number	Regenerant Volume		Phosphorus Content (mg/l)	Phosphorus Recovered (grams)	Incremental Phosphorus Recovery (ΔP, grams)	ΔP per Incremental Regenerant Volume (g/Igal)	Percent of Total Phosphorus Recovered
	Bed Volumes per column	Igal					
8	1	2	120.3	1.09	1.09	0.55	25.1
	2.5	5	103.8	2.36	1.27	0.42	54.4
	3.8	7.5	86.3	2.94	0.58	0.23	67.7
	7.5	15	66.3	4.52	1.58	0.21	104.1
	10.0	20	47.8	4.34	- 0.18	-	100.0
13	1	2.5	345.5	3.92	3.92	1.57	17.2
	2	5	381.0	8.65	4.73	1.89	38.0
	3	7.5	329.5	11.22	2.57	1.03	49.3
	6	15	250.5	17.06	5.84	0.78	75.0
	9	22.5	233.5	23.85	6.79	0.91	104.8
	12	30	167.0	22.75	- 1.10	-	100.0

Regeneration 8: 1N NaOH (twice treated with lime); Initial Phosphorus Content = 13.7 mg/l

Regeneration 13: 2N NaOH; Initial Phosphorus Content = 80.5 mg/l
Two columns regenerated simultaneously

Regeneration of the alumina columns will result in the discharge of a small volume (approximately 10 B.V.) of relatively concentrated waste resulting from the rinsing operation. The aluminum and phosphorus content of typical rinsewater samples is shown in Figure 12.

Methods of treatment for this waste stream were investigated in the laboratory. The results, as summarized in Table 10, indicate that the aluminum and phosphorus can be reduced by more than 90 percent by neutralization to pH 7. The sludge production would be about 20 percent of the rinsewater volume. It is visualized that the rinsewater would be contained during the regeneration process and slowly added to the raw sewage at a rate which would maintain a neutral pH in the primary clarifier. The sludge would be recovered and disposed of along with the primary sludge. Lime addition would also result in phosphorus precipitation from concentrated rinsewater. The resultant sludge production would be 6 to 7 percent of the treated rinsewater volume.

6.3 Discussion of Lime Precipitation Process

The laboratory investigations of the lime precipitation process indicated that the removal efficiency was increased at high dosages and longer contact times. Although the improvement was marginal, maximum removal was attained at a dosage of 8 g $Ca(OH)_2$ per litre of regenerant and a contact time of six hours.

The initial pilot scale lime treatment of a phosphorus laden regenerant solution at a dosage of 8 g lime/l and two hours of contact time resulted in only 53 percent removal. Subsequently, the contact time was increased to four hours which resulted in removals approaching those predicted by the laboratory results (88.5 and 97.4 percent). Negligible losses of sodium hydroxide were observed after lime treatment of the caustic solution.

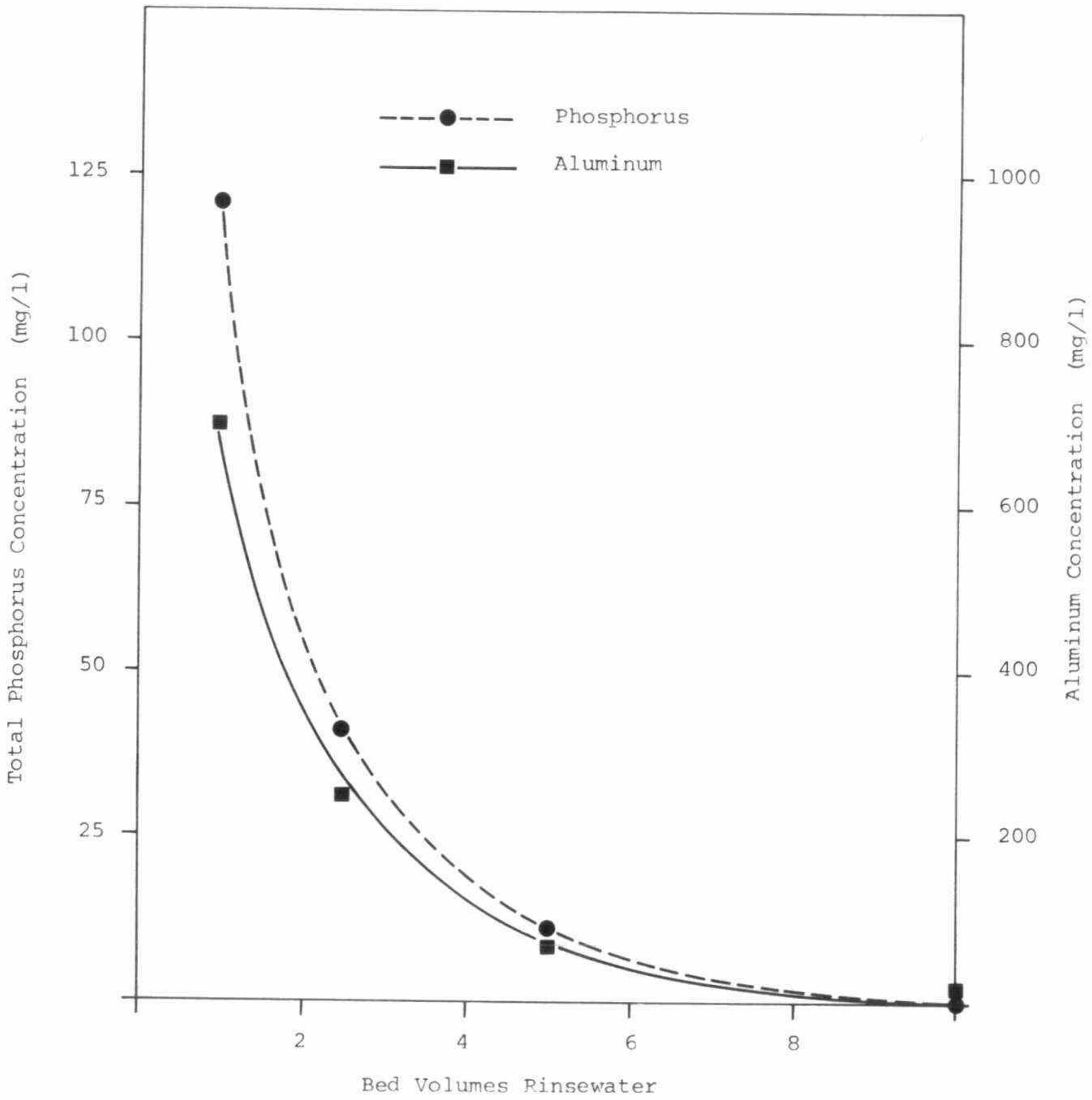

Figure 12. PHOSPHORUS AND ALUMINUM CONTENT OF RINSEWATER AFTER COLUMN REGENERATION

Data From Regeneration 2

TABLE 10 TREATMENT OF CAUSTIC RINSEWATER FROM REGENERATED ACTIVATED ALUMINA COLUMNS - LABORATORY STUDIES

Sample Description	Lime Dosage (g/l)	Stirring Time (minutes)	Concentration (mg/l)		Phosphorus Removal (%)	Sludge Production (Volume %)
			Phosphorus	Aluminum		
Untreated Rinsewater	-	-	59.0	120	-	-
Neutralized Rinse-water (pH 7)	0	30	1.4	10	97.6	20
Lime Treated	0.5	30	2.3	70	96.1	7
Lime Treated	1.0	30	0.8	55	98.6	6
Lime Treated	2.0	30	0.7	48	98.8	6
Lime Treated	0.5	120	1.6	65	97.3	7
Lime Treated	1.0	120	0.5	44	99.2	6
Lime Treated	2.0	120	0.2	18	99.7	6

Sludge production from the process varied from 2.0 to 5.5 percent by volume. The supernatant was essentially free of solids and did not require any filtration prior to reuse. The fourth lime treatment of the regenerant removed 91.0 percent of the phosphorus; however, the sludge was 67 percent of the total volume. Extensive laboratory studies, including prolonged stirring and increased lime dosage, did not improve the sludge settleability. Further investigations of the long-term effects of the lime precipitation process on the reuseability of the regenerant solution appear to be necessary.

7. ECONOMIC EVALUATION OF PROCESS FEASIBILITY

The technical feasibility of the activated alumina process for adsorption of phosphorus has been demonstrated by the pilot scale investigation. From the results of the study, cost estimates have been developed for the polishing of 1 MIGPD of chemically treated secondary effluent. The capital cost estimates were based on the following assumptions:

- average phosphorus content of the activated alumina column feed of 1 mg/l;
- average phosphorus content of the activated alumina column effluent of 0.2 mg/l;
- nominal contact time per column of 2.5 minutes;
- three column system operated in an upflow mode;
- filtration of the chemically treated secondary effluent prior to activated alumina polishing;
- regeneration of the spent activated alumina using once through elution with 15 bed volumes 1N NaOH; and,
- rinsewater (10 bed volumes) storage and addition to the primary clarifier for sludge recovery.

The capital cost of the activated alumina contact columns was estimated from 1972 costs for an activated carbon system (Process Design Manual for Carbon Adsorption, EPA, 1973), upgraded to 1975 prices. The costs of initial activated alumina and sodium hydroxide changes were obtained from local suppliers, f.o.b. the production site.

The operating cost estimates were calculated with the following assumptions:

- operational adsorptive capacity of 3 milligrams phosphorus per gram of activated alumina;

- make-up alumina requirement of 10 percent per cycle;
- sodium hydroxide make-up following column regeneration contained in one bed volume for each regeneration cycle;
- lime treatment of the caustic solution required every second regeneration cycle at a dosage of 8 grams of lime per litre of regenerant;
- sodium hydroxide make-up after lime treatment equivalent to the volume lost due to sludge production (3 percent of regenerant solution); and,
- disposal of sludge resulting from activated alumina make-up (10 percent of column per cycle), lime treatment (3 percent of regenerant volume) and rinsewater neutralization (10 percent of rinsewater volume after digestion).

The operating costs do not include maintenance and power costs. The chemical costs for activated alumina, sodium hydroxide, and lime were based on current prices obtained from local suppliers. Sludge disposal costs were assumed to be $1.25 per cubic yard.

Capital costs of an installation for the treatment of 1 MIGPD were estimated to be $141,000, i.e. higher than the estimates made following the laboratory study. The majority of the cost increase is related to the need for a filtration system, as determined during the pilot plant operation.

Operating costs of the system were estimated to be $113.70 per MIG which is also higher than the previous estimate. This increase is due to the lower operational capacity of the activated alumina, determined in the pilot scale study, and, subsequently, more frequent regenerations. Also, the more rapid loss of adsorptive capacity than observed during the laboratory study results in higher alumina make-up requirements.

The itemized capital and operating cost estimates are as follows:

I. Capital Cost Estimate

Dual media filtration including backwash system, air scour, etc.	$ 40,000
Pumping Station for filter and activated alumina system	$ 4,500
Activated Alumina Columns, upflow expanded bed, 280 ft^3 per bed including piping, valves, instrumentation, etc.	$ 30,000
Regeneration System, including caustic tanks, pumps, rinsewater holding tanks, lime-mixing equipment, etc.	$ 50,000
Initial Activated Alumina charge; 46,000 lb @ $0.32/lb	$ 14,700
Initial sodium hydroxide charge; 10,400 lb @ $17.50/CWT	$ 1,800
TOTAL CAPITAL COST	$141,000

II. Operating Cost Estimate (per Million Imperial Gallons)

Activated alumina make-up, at 10 percent per cycle, @ $0.32/lb	$ 85.90
Sodium Hydroxide losses, 1 B.V. of 1N NaOH per regeneration cycle @ $17.50/CWT	$ 21.30
Sodium Hydroxide losses after lime treatment (3 percent of regenerant volume) @ $17.50/CWT	$ 0.50
Lime regeneration, dosage 8 g/l @ $32.50/ton	$ 3.00
Sludge disposal @ $1.25/cu yd	
Lime sludge	$ 0.50
Waste activated alumina	$ 0.25
Rinsewater sludge	$ 2.25
TOTAL OPERATING COST (per MIG)	$113.70

ACKNOWLEDGEMENTS

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- Mr. Earl Haye and the staff at the Waterloo Water Pollution Control Plant for their co-operation during the study.

LIST OF ABBREVIATIONS

Al_2O_3	Activated alumina
B.V. avg.	Average bed volume
C	Effluent concentration
Co	Feed concentration
$Ca(OH)_2$	Hydrated lime
cu yd	cubic yard
CWT	Hundred Weight
EPA	Environmental Protection Agency
ft^3	cubic feet
g	gram
hr	hour
IJC	International Joint Commission
Igal	Imperial gallon
Igpm	Imperial gallons per minute
l	litre
lb	pound
mg	milligram
MIG	Million Imperial gallons
MIGPD	Million Imperial gallons per day
min	minute
mm	millimetre
N	Normal
NaOH	Sodium hydroxide
P	Phosphorus
U.S.	United States
Δ	Incremental change
%	percent

APPENDIX I

PICTORIAL DESCRIPTION OF ACTIVATED ALUMINA PILOT PLANT

APPENDIX I

PICTORIAL DESCRIPTION OF ACTIVATED ALUMINA PILOT PLANT

Chemically pretreated secondary effluent from the Waterloo Water Pollution Control Plant was fed with a submersible pump from upstream of the chlorine contact chamber to the pressure filter head tank (Plate 1).

The dual media pressure filter was operated daily at low hydraulic loadings to maintain a supply of polished effluent in the 1,000 gallon effluent reservoirs (Plate 2).

The filtered secondary effluent was fed by gravity to the activated alumina feed tank (Plate 3). Feed was maintained to the activated alumina columns by a centrifugal feed pump, equipped with a bypass for protection of the system, and monitored periodically by means of a rotameter.

The first and third activated alumina columns (Plate 4) were operated in series in an upflow mode. The second column was maintained as a standby throughout the study.

Polished effluent from the system was collected in a final holding tank to be used as rinsewater for the columns following regeneration (Plate 5). Alternatively, freshwater from this tank could be used to flush the spent regenerant from the system.

A separate centrifugal feed pump and rotameter was provided for regeneration of the saturated activated alumina columns, and rinsing following regeneration. For regenerations involving large volumes of sodium hydroxide solutions, a 150 Igal polyethylene storage tank was provided (Plate 6).

During regeneration runs involving small volumes of caustic solution, a small holding tank could be substituted, (Plate 7), to provide wide versatility for this phase of the investigation.

The activated alumina system during a typical saturation cycle is shown in Plate 8.

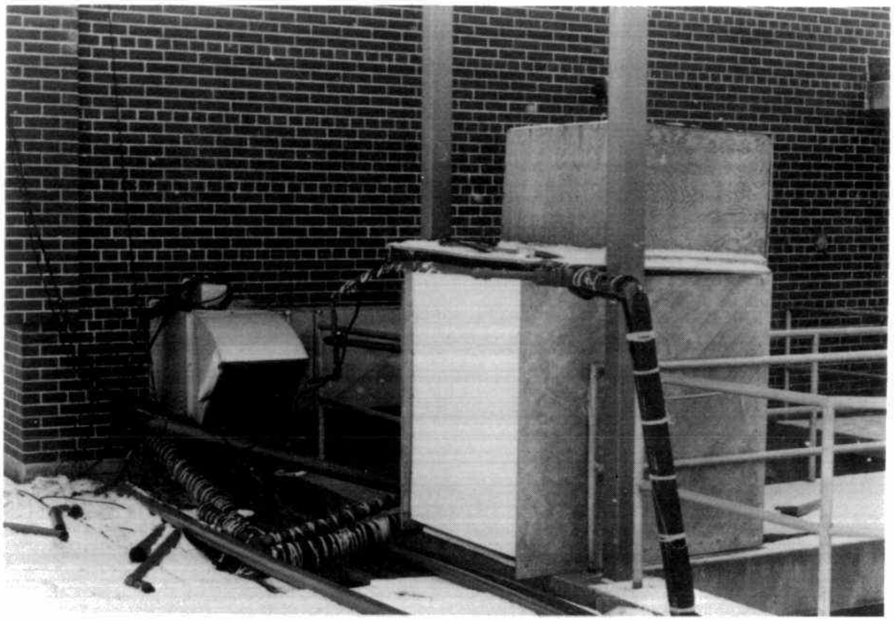

Plate 1: Filter Head Tank

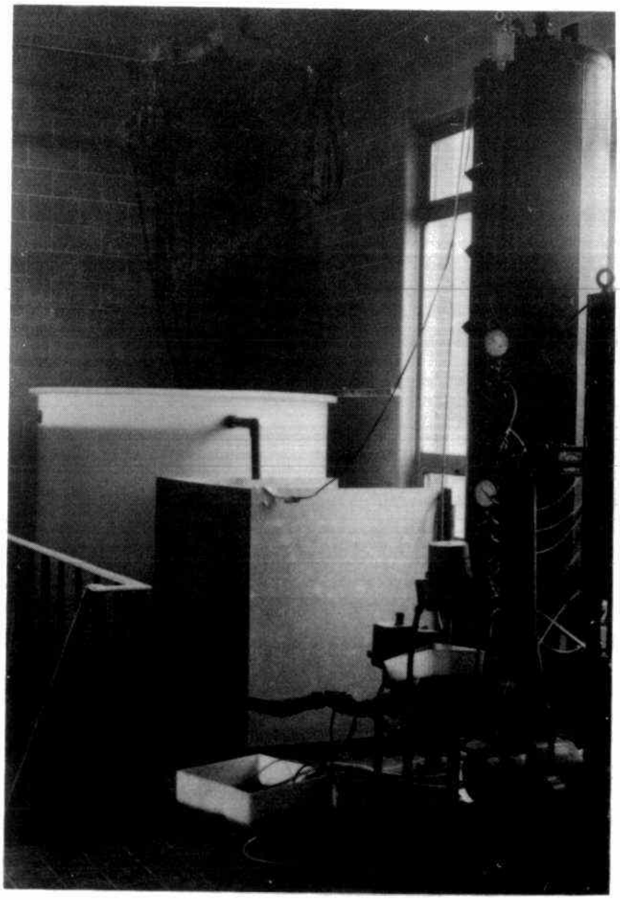

Plate 2: Filter System and Filtered Effluent Reservoir

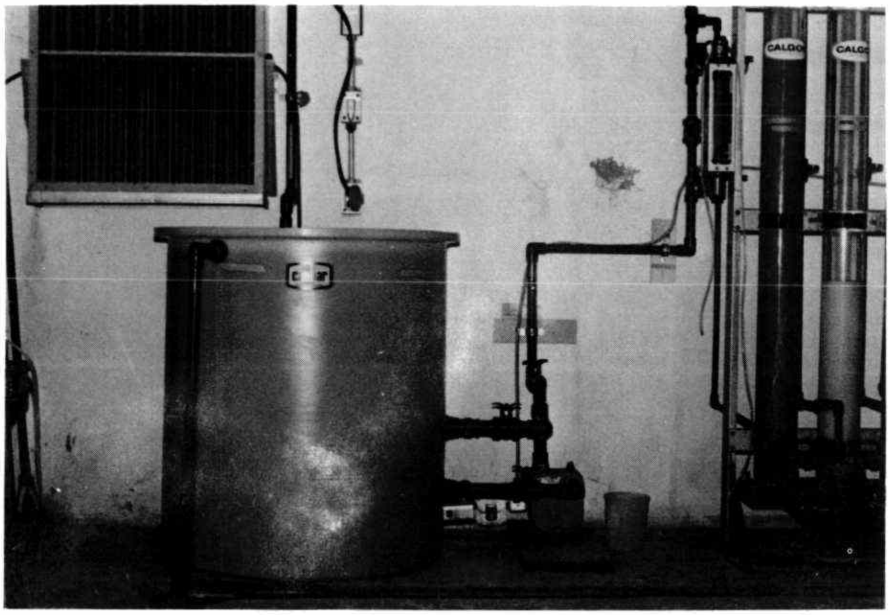

Plate 3: Activated Alumina Feed System

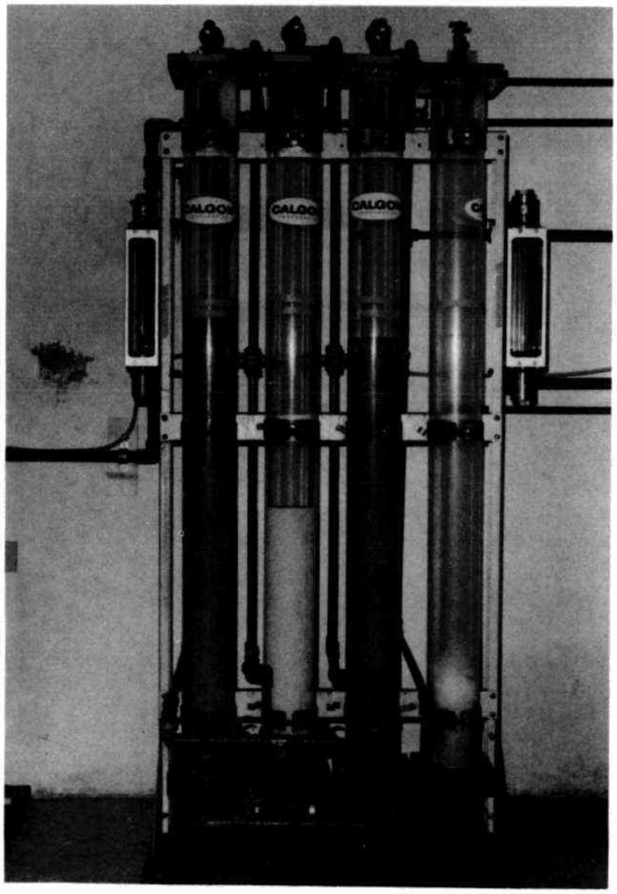

Plate 4: Activated Alumina Columns

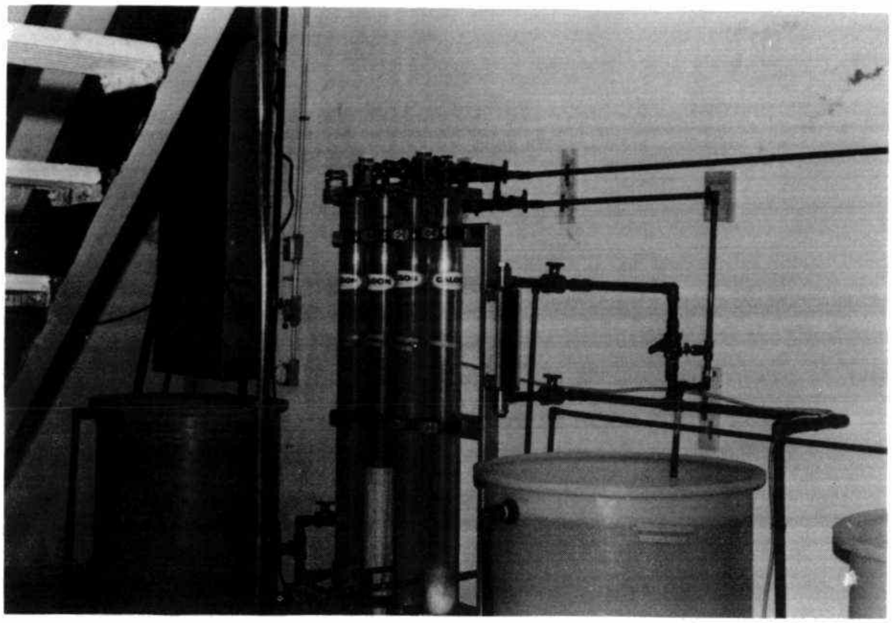

Plate 5: Activated Alumina Feed and Effluent System

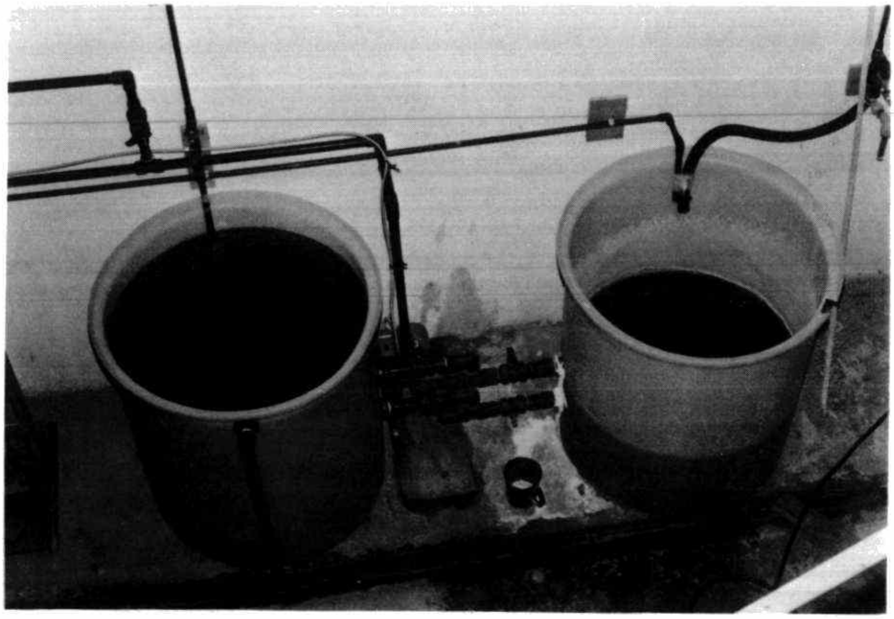

Plate 6: Rinsewater and Regenerant Storage and Feed Systems

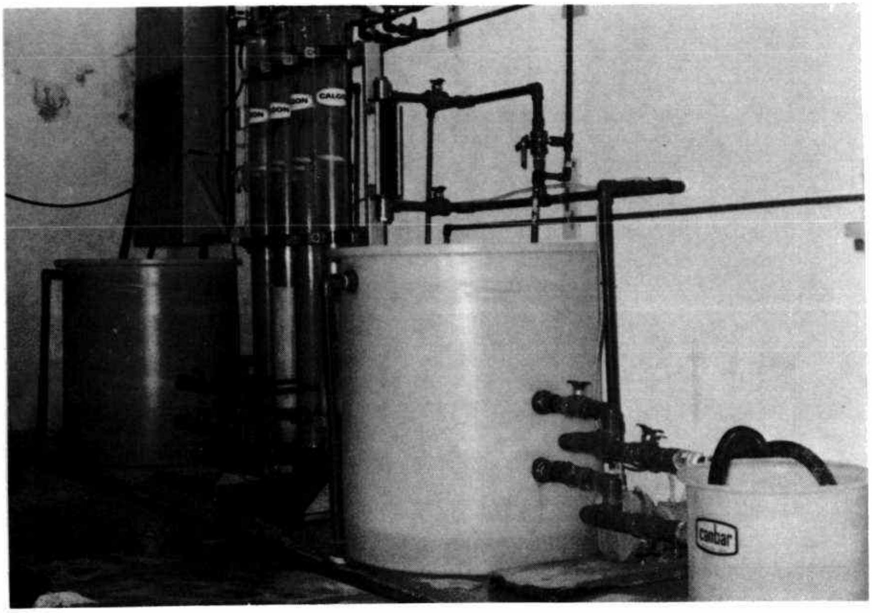

Plate 7: Regeneration System for Small Caustic Volumes

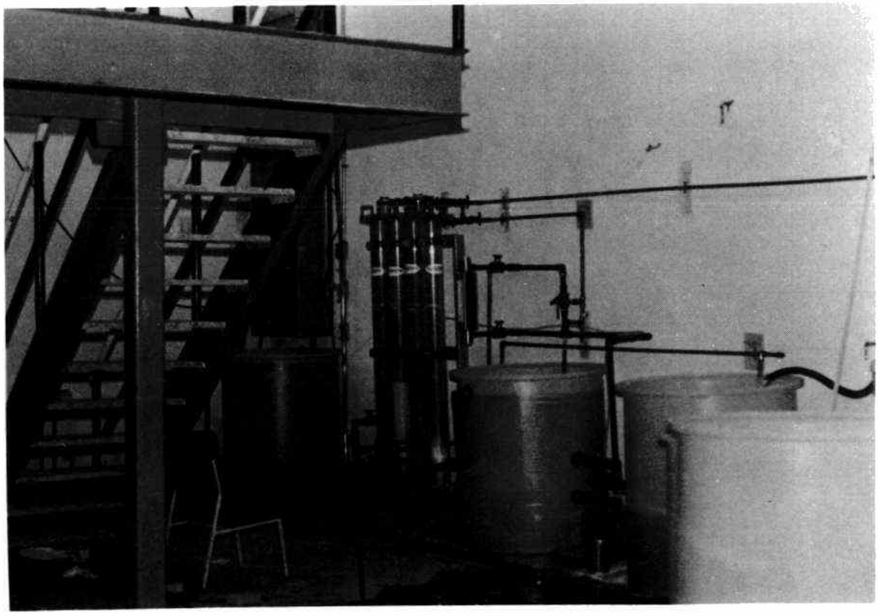

Plate 8: Activated Alumina Pilot Plant System

APPENDIX II

SUMMARY OF SATURATION DATA

PERFORMANCE OF ACTIVATED ALUMINA COLUMNS

Column Number 1

Saturation Cycle Number 1

Date: October 7 - October 18, 1974

Activated Alumina in Column = 6,800 g

Unexpanded Bed Volume = 0.32 ft^3 (2.0 Igal)

Column Feed Rate = 0.90 Igpm

Nominal Contact Time = 2.2 minutes

Position of Column in Series	Run Time (Days)	Bed Volumes	Orthophosphate Concentration (mg P/l)	
			Column Feed	Column Effluent
First	0	0	0.49	-
First	0.08	52	0.52	0.14
First	0.33	214	0.59	0.16
First	0.75	486	0.51	0.14
First	4.0	2,592	0.28	0.14
First	4.8	3,110	1.60	0.20
First	5.1	3,305	1.15	0.12
First	5.8	3,758	0.14	0.10
First	8.0	5,184	1.12	0.32
First	8.5	5,508	2.11	0.53
First	10.0	6,480	1.31	0.89

Results:

Total Orthophosphate in Feed (as P) = 48.00 g

Phosphorus adsorbed during Run = 32.44 g

PERFORMANCE OF ACTIVATED ALUMINA COLUMNS

Column Number 3

Saturation Cycle Number 1

Date: October 7 - October 23, 1974

Activated Alumina in Column = 6,800 g

Unexpanded Bed Volume = 0.32 ft^3 (2.0 Igal)

Column Feed Rate = 0.90 Igpm

Nominal Contact Time = 2.2 minutes

Position of Column in Series	Run Time (Days)	Bed Volumes	Orthophosphate Concentration (mg P/l) Column Feed	Column Effluent
Second	0	0	-	-
Second	0.08	52	0.14	0.07
Second	0.33	214	0.16	0.14
Second	0.75	486	0.14	0.11
Second	4.0	2,592	0.14	0.08
Second	4.8	3,110	0.20	0.10
Second	5.1	3,305	0.12	0.07
Second	5.8	3,758	0.10	0.05
Second	8.0	5,184	0.32	0.15
Second	8.5	5,508	0.53	0.07
Second	10.0	6,480	0.89	0.36
First	11.5	7,452	1.20	0.49
First	12.2	7,906	1.22	0.61
First	12.5	8,100	1.55	0.84
First	13.0	8,424	1.42	0.91
First	13.5	8,748	2.02	1.02
First	14.0	9,072	2.35	1.48
First	14.5	9,396	2.16	1.36
First	15.0	9,720	2.49	1.87
First	15.5	10,040	2.01	1.81
First	16.0	10,368	2.28	1.92

Results:

Total Orthophosphate in Feed (as P) = 75.97 g

Phosphorus adsorbed during Run = 31.90 g

PERFORMANCE OF ACTIVATED ALUMINA COLUMNS

Column Number 1

Saturation Cycle Number 2

Date: October 18 - October 23, 1974

Activated Alumina in Column = 6,500 g

Unexpanded Bed Volume = 0.32 ft^3 (2.0 Igal)

Column Feed Rate = 0.90 Igpm

Nominal Contact Time = 2.2 minutes

Position of Column in Series	Run Time (Days)	Bed Volumes	Orthophosphate Concentration (mg P/l)	
			Column Feed	Column Effluent
Second	0	0	0.49	0.14
Second	0.67	434	0.61	0.08
Second	1.0	648	0.84	0.14
Second	1.5	972	0.91	0.15
Second	2.0	1,296	1.02	0.18
Second	2.5	1,620	1.48	0.36
Second	3.0	1,944	1.36	0.32
Second	3.5	2,268	1.87	0.67
Second	4.0	2,592	1.81	0.81
Second	4.5	2,916	1.92	1.07

Results:

Total Orthophosphate in Feed (as P) = 32.52 g

Phosphorus adsorbed during Run = 22.87 g

PERFORMANCE OF ACTIVATED ALUMINA COLUMNS

Column Number 3

Saturation Cycle Number 2

Date: October 23 - October 29, 1974

Activated Alumina in Column = 6,660 g

Unexpanded Bed Volume = 0.32 ft^3 (2.0 Igal)

Column Feed Rate = 0.9 Igpm

Nominal Contact Time = 2.2 minutes

Position of Column in Series	Run Time (Days)	Bed Volumes	Orthophosphate Concentration (mg P/l)	
			Column Feed	Column Effluent
Second	0	0	-	-
Second	0.2	130	0.26	0.08
Second	0.75	486	0.32	0.12
Second	1.33	862	0.33	0.11
Second	1.75	1,134	0.41	0.12
Second	2.75	1,782	1.21	0.15
Second	3.25	2,100	1.47	0.22
Second	3.75	2,430	1.63	0.29
Second	4.30	2,786	1.63	0.35
Second	4.75	3,080	1.63	0.37
Second	5.25	3,400	1.63	0.39
Second	5.75	3,726	1.92	0.39

Results:

Total Orthophosphate in Feed (as P) = 36.63 g

Phosphorus adsorbed during Run = 29.15 g

PERFORMANCE OF ACTIVATED ALUMINA COLUMNS

Column Number 1

Saturation Cycle Number 3

Date: October 23 - October 29, 1974

Activated Alumina in Column = 6,360 g

Unexpanded Bed Volume = 0.32 ft^3 (2.0 Igal)

Column Feed Rate = 0.90 Igpm

Nominal Contact Time = 2.2 minutes

Position of Column in Series	Run Time (Days)	Bed Volumes	Orthophosphate Concentration (mg P/1)	
			Column Feed	Column Effluent
First	0	0	2.6	-
First	0.2	130	2.6	0.26
First	0.75	486	2.6	0.32
First	1.33	862	2.6	0.33
First	1.75	1,134	2.25	0.41
First	2.75	1,782	2.58	1.21
First	3.25	2,100	2.6	1.47
First	3.75	2,430	2.58	1.63
First	4.30	2,786	2.22	1.63
First	4.75	3,080	2.25	1.63
First	5.25	3,400	2.12	1.63
First	5.75	3,726	2.12	1.92

Results:

Total Orthophosphate in Feed (as P) = 82.32 g

Phosphorus adsorbed during Run = 46.18 g

PERFORMANCE OF ACTIVATED ALUMINA COLUMNS

Column Number 3

Saturation Cycle Number 3

Date: October 29 - November 8, 1974

Activated Alumina in Column = 6,635 g

Unexpanded Bed Volume = 0.32 ft^3 (2.0 Igal)

Column Feed Rate = (Initial 3,100 B.V. - 0.60 Igpm)
(Final 900 B.V. - 0.50 Igpm)

Nominal Contact Time = (3.3 minutes @ 0.60 Igpm)
(4.0 minutes @ 0.50 Igpm)

Position of Column in Series	Run Time (Days)	Bed Volumes	Orthophosphate Concentration (mg P/l)	
			Column Feed	Column Effluent
Second	0.33	143	0.24	0.29
Second	0.75	324	0.26	0.12
Second	1.33	575	0.07	0.03
Second	1.75	756	0.35	0.12
Second	2.10	907	0.28	0.17
Second	2.5	1,080	0.50	0.17
Second	3.33	1,440	0.34	0.12
Second	3.9	1,685	0.28	0.14
Second	4.33	1,870	0.30	0.14
Second	4.9	2,117	0.30	0.17
Second	5.2	2,246	0.33	0.17
Second	5.8	2,506	0.40	0.14
Second	6.2	2,678	0.52	0.17
Second	6.8	2,938	0.78	0.20
First	7.2	3,110	1.74	0.50
First	7.4	3,182	3.06	0.81
First	7.8	3,316	2.59	1.01
First	8.7	3,640	0.76	0.71
First	9.15	3,812	0.10	0.33
First	9.7	4,010	0.34	0.53

Results:

Total Orthophosphate in Feed (as P) = 22.69 g

Phosphorus adsorbed during Run = 12.14 g

PERFORMANCE OF ACTIVATED ALUMINA COLUMNS

Column Number 1

Saturation Cycle Number 4

Date: October 29 - November 5, 1974

Activated Alumina in Column = 6,335 g

Unexpanded Bed Volume = 0.32 ft^3 (2.0 Igal)

Column Feed Rate = 0.60 Igpm

Nominal Contact Time = 3.3 minutes

Position of Column in Series	Run Time (Days)	Bed Volumes	Orthophosphate Concentration (mg P/l)	
			Column Feed	Column Effluent
First	0.33	143	1.62	0.24
First	0.75	324	1.50	0.26
First	1.33	575	0.12	0.07
First	1.75	756	1.06	0.35
First	2.10	907	1.62	0.28
First	2.5	1,080	1.28	0.50
First	3.33	1,440	0.14	0.34
First	3.9	1,685	0.38	0.28
First	4.33	1,870	0.38	0.30
First	4.9	2,117	0.56	0.30
First	5.2	2,246	0.92	0.33
First	5.8	2,506	1.00	0.40
First	6.2	2,678	1.74	0.52
First	6.8	2,938	1.74	0.78

Results:

Total Orthophosphate in Feed (as P) = 24.59 g

Phosphorus adsorbed during Run = 16.11 g

PERFORMANCE OF ACTIVATED ALUMINA COLUMNS

Column Number 1

Saturation Cycle Number 5

Date: November 5 - November 29, 1974

Activated Alumina in Column = 6,320 g

Unexpanded Bed Volume = 0.32 ft^3 (2.0 Igal)

Column Feed Rate = 0.5 Igpm

Nominal Contact Time = 4.0 minutes

Positon of Column in Series	Run Time (Days)	Bed Volumes	Orthophosphate Concentration (mg P/l)	
			Column Feed	Column Effluent
Second	0	0	0.81	0.55
Second	0.4	144	1.01	0.39
Second	1.3	468	0.71	0.27
Second	1.75	630	0.33	0.20
Second	2.3	828	0.53	0.26
First	3.3	1,188	0.25	0.25
First	3.8	1,368	0.30	0.26
First	4.3	1,548	0.16	0.19
First	4.8	1,728	0.24	0.15
First	5.1	1,836	0.13	0.16
First	5.8	2,088	0.23	0.16
First	6.3	2,268	0.85	0.20
First	7.05	2,538	0.50	0.32
First	7.8	2,808	0.20	0.25
First	8.3	2,988	0.22	0.23
First	8.8	3,168	0.25	0.23
First	9.3	3,348	0.17	0.20
First	9.8	3,528	0.10	0.15
First	10.3	3,708	0.08	0.17
First	10.8	3,888	0.17	0.14
First	11.3	4,068	0.43	0.11
First	11.8	4,248	0.39	0.20
First	12.3	4,428	0.44	0.22
First	12.8	4,608	2.30	0.39
First	13.55	4,878	0.61	0.41
First	14.05	5,058	0.92	0.55
First	15.00	5,400	0.22	0.41
First	15.05	5,420	0.11	0.40
First	15.3	5,508	0.52	0.29

Results:

Total Orthophosphate in Feed (as P) = 24.79 g

Phosphorus adborbed during Run = 11.86 g

PERFORMANCE OF ACTIVATED ALUMINA COLUMNS

Column Number 3

Saturation Cycle Number 4

Date: November 8 - December 4, 1974

Activated Alumina in Column = 6,580 g

Unexpanded Bed Volume = 0.32 ft^3 (2.0 Igal)

Column Feed Rate = 0.5 Igpm

Nominal Contact Time = 4.0 minutes

Position of Column in Series	Run Time (Days)	Bed Volumes	Orthophosphate Concentration (mg P/l)	
			Column Feed	Column Effluent
Second	0	0	0.25	-
Second	0.5	180	0.26	0.11
Second	1.0	360	0.19	0.25
Second	1.5	540	0.15	0.13
Second	1.8	648	0.16	0.16
Second	2.5	900	0.16	0.17
Second	3.0	1,080	0.20	0.14
Second	3.75	1,350	0.32	0.16
Second	4.5	1,620	0.25	0.15
Second	5.0	1,800	0.23	0.15
Second	5.5	1,980	0.23	0.16
Second	6.0	2,160	0.20	0.14
Second	6.5	2,340	0.15	0.11
Second	7.0	2,520	0.17	0.13
Second	7.5	2,700	0.14	0.14
Second	8.0	2,880	0.11	0.04
Second	8.5	3,060	0.20	0.11
Second	9.0	3,240	0.22	0.11
Second	9.5	3,420	0.39	0.25
Second	10.25	3,690	0.41	0.20
Second	10.75	3,870	0.55	0.17
Second	11.7	4,212	0.41	0.31
Second	11.75	4,230	0.40	0.28
Second	12.0	4,320	0.29	0.28
First	12.75	4,590	0.29	0.28
First	13.1	4,716	0.26	0.11
First	13.6	4,896	0.48	0.21
First	14.1	5,076	0.75	0.13
First	14.6	5,256	0.72	0.40
First	15.1	5,436	0.94	0.43
First	15.6	5,616	0.88	0.66
First	16.1	5,796	1.34	0.74
First	16.6	5,976	1.20	0.82
First	17.1	6,156	1.22	0.86
First	17.6	6,336	0.74	0.47

Results:

Total Orthophosphate in Feed (as P) = 26.89 g
Phosphorus adsorbed during Run = 12.63 g

PERFORMANCE OF ACTIVATED ALUMINA COLUMNS

Column Number 1

Saturation Cycle Number 6

Date: November 29 - December 13, 1974

Activated Alumina in Column = 6,280 g

Unexpanded Bed Volume = 0.32 ft^3 (2.0 Igal)

Column Feed Rate = 0.5 Igpm

Nominal Contact Time = 4.0 minutes

Position of Column in Series	Run Time (Days)	Bed Volumes	Orthophosphate Concentration (mg P/l)	
			Column Feed	Column Effluent
Second	0	0	0.11	0.08
Second	0.5	180	0.21	0.15
Second	1.0	360	0.13	0.16
Second	1.5	540	0.40	0.15
Second	2.0	720	0.43	0.22
Second	2.5	900	0.66	0.30
Second	3.0	1,080	0.74	0.24
Second	3.5	1,260	0.82	0.33
Second	4.0	1,440	0.86	0.35
Second	4.5	1,620	0.47	0.21
First	5.5	1,980	0.95	0.29
First	6.0	2,160	0.75	0.25
First	6.5	2,340	0.42	0.27
First	7.0	2,520	0.42	0.28
First	7.5	2,700	0.22	0.24
First	8.0	2,880	0.69	0.28
First	8.5	3,060	1.05	0.43
First	9.0	3,240	1.28	0.59
First	9.5	3,420	0.89	0.36
First	10.0	3,600	0.64	0.61
First	10.5	3,780	0.61	0.60
First	11.0	3,960	0.34	0.43
First	11.5	4,140	0.32	0.45

Results:

Total Orthophosphate in Feed (as P) = 21.01 g

Phosphorus adsorbed during Run = 10.67 g

PERFORMANCE OF ACTIVATED ALUMINA COLUMNS

Column Number 3

Saturation Cycle Number 5

Date: December 4 - December 24, 1974

Activated Alumina in Column = 6,560 g

Unexpanded Bed Volume = 0.32 ft^3 (2.0 Igal)

Column Feed Rate = 0.5 Igpm

Nominal Contact Time = 4.0 minutes

Position of Column in Series	Run Time (Days)	Bed Volumes	Orthophosphate Concentration (mg P/l)	
			Column Feed	Column Effluent
Second	0	0	0.41	0.13
Second	1.0	360	0.29	0.23
Second	1.5	540	0.25	0.19
Second	2.0	720	0.27	0.20
Second	2.5	900	0.28	0.19
Second	3.0	1,080	0.24	0.14
Second	3.5	1,260	0.28	0.23
Second	4.0	1,440	0.43	0.23
Second	4.5	1,620	0.59	0.24
Second	5.0	1,800	0.36	0.25
Second	5.5	1,980	0.61	0.08
Second	6.0	2,160	0.60	0.20
Second	6.5	2,340	0.43	0.28
Second	7.0	2,520	0.45	0.29
First	7.5	2,700	0.50	0.30
First	9.5	3,420	0.97	0.41
First	10.0	3,600	0.90	0.40
First	10.5	3,780	1.16	0.58
First	11.0	3,960	1.38	0.54
First	11.5	4,140	0.98	0.57
First	12.0	4,320	1.03	0.61
First	12.5	4,500	0.95	0.70
First	13.0	4,680	0.83	0.64
First	14.0	5,040	0.78	0.64
First	15.0	5,400	1.26	0.77
First	15.5	5,580	0.89	0.74
First	16.0	5,760	0.93	0.80
First	16.5	5,940	1.16	0.78
First	17.0	6,120	0.91	0.86

Results:

Total Orthophosphate in Feed (as P) = 39.11 g

Phosphorus adsorbed during Run = 15.92 g

PERFORMANCE OF ACTIVATED ALUMINA COLUMNS

Column Number 1

Saturation Cycle Number 7

Date: December 13 - December 28, 1974

Activated Alumina in Column = 6,270 g

Unexpanded Bed Volume = 0.32 ft^3 (2.0 Igal)

Column Feed Rate = 0.5 Igpm

Nominal Contact Time = 4.0 minutes

Position of Column in Series	Run Time (Days)	Bed Volumes	Orthophosphate Concentration (mg P/l)	
			Column Feed	Column Effluent
Second	0	0	0.30	0.18
Second	2.0	720	0.41	0.37
Second	2.5	900	0.40	0.16
Second	3.0	1,080	0.58	0.19
Second	3.5	1,260	0.54	0.21
Second	4.0	1,440	0.57	0.22
Second	4.5	1,620	0.61	0.18
Second	5.0	1,800	0.70	0.27
Second	5.5	1,980	0.64	0.27
Second	6.5	2,340	0.64	0.32
Second	7.5	2,700	0.77	0.43
Second	8.0	2,880	0.74	0.35
Second	8.5	3,060	0.80	0.42
Second	9.0	3,240	0.78	0.38
Second	9.5	3,420	0.86	0.59
First	10.0	3,600	1.04	0.56
First	13.0	4,680	0.38	0.40
First	13.5	4,860	1.02	0.55

Results:

Total Orthophosphate in Feed (as P) = 27.96 g

Phosphorus adsorbed during Run = 12.47 g

PERFORMANCE OF ACTIVATED ALUMINA COLUMNS

Column Number 3

Saturation Cycle Number 6

Date: December 24 - January 9, 1975

Activated Alumina in Column = 6,550 g

Unexpanded Bed Volume = 0.32 ft^3 (2.0 Igal)

Column Feed Rate = 0.5 Igpm

Nominal Contact Time = 4.0 minutes

Position of Column in Series	Run Time (Days)	Bed Volumes	Orthophosphate Concentration (mg P/l)	
			Column Feed	Column Effluent
Second	0.5	180	0.56	0.28
Second	3.5	1,260	0.40	0.22
Second	4.0	1,440	0.55	0.27
First	5.5	1,980	-	0.32
First	6.0	2,160	0.94	0.35
First	6.5	2,340	1.33	0.64
First	7.0	2,520	1.01	0.63
First	7.1	2,556	0.81	0.62
First	9.0	3,240	1.54	0.67
First	9.5	3,420	1.49	0.76
First	10.0	3,600	1.45	1.02
First	10.5	3,780	1.61	0.76
First	11.5	4,140	1.04	0.94
First	12.0	4,320	1.23	1.02
First	12.5	4,500	1.23	1.03
First	13.0	4,680	2.20	1.57
First	13.5	4,860	2.09	1.61
First	14.0	5,040	1.90	1.80
First	14.5	5,220	1.44	1.47
First	15.0	5,400	1.19	1.09

Results:

Total Orthophosphate in Feed (as P) = 48.94 g

Phosphorus adsorbed during Run = 19.01 g

PERFORMANCE OF ACTIVATED ALUMINA COLUMNS

Column Number 1

Saturation Cycle Number 8

Date: December 28 - January 9, 1975

Activated Alumina in Column = 6,265 g

Unexpanded Bed Volume = 0.32 ft^3 (2.0 Igal)

Column Feed Rate = 0.5 Igpm

Nominal Contact Time = 4.0 minutes

Position of Column in Series	Run Time (Days)	Bed Volumes	Orthophosphate Concentration (mg P/l)	
			Column Feed	Column Effluent
Second	1.0	360	0.32	-
Second	1.75	630	0.35	-
Second	2.25	810	0.64	0.08
Second	2.75	990	0.63	0.05
Second	2.85	1,026	0.62	0.09
Second	4.75	1,710	0.67	0.32
Second	5.25	1,890	0.76	0.24
Second	5.75	2,070	1.02	0.48
Second	6.25	2,250	0.76	0.48
Second	7.25	2,610	0.94	0.60
Second	7.75	2,790	1.02	0.64
Second	8.25	2,970	1.03	0.92
Second	8.75	3,150	1.57	0.93
Second	9.25	3,330	1.61	1.08
Second	9.75	3,510	1.80	1.36
Second	10.25	3,690	1.47	0.89
Second	10.75	3,870	1.09	0.79

Results:

Total Orthophosphate in Feed (as P) = 30.61 g

Phosphorus adsorbed during Run = 14.34 g

PERFORMANCE OF ACTIVATED ALUMINA COLUMNS

Column Number 1

Saturation Cycle Number 9

Date: January 9 - January 24, 1975

Activated Alumina in Column = 7,940 g

Unexpanded Bed Volume = 0.40 ft^3 (2.5 Igal)

Column Feed Rate = 0.50 Igpm

Nominal Contact Time = 5.0 minutes

Position of Column in Series	Run Time (Days)	Bed Volumes	Orthophosphate Concentration (mg P/l)	
			Column Feed	Column Effluent
First	0.5	144	0.30	0.08
First	0.75	216	0.43	0.08
First	2.0	576	1.61	0.27
First	3.0	864	1.10	0.32
First	3.5	1,008	0.83	0.32
First	4.0	1,152	-	0.30
First	4.5	1,296	0.93	0.33
First	5.0	1,440	0.90	0.41
First	5.5	1,584	0.90	0.42
First	6.0	1,728	0.43	0.45
First	6.5	1,872	0.69	0.41
First	7.0	2,016	0.64	0.43
First	7.5	2,160	0.59	0.41
First	8.5	2,448	0.62	0.42
First	9.5	2,736	0.65	0.47
First	10.0	2,880	0.61	0.46
First	10.5	3,024	0.81	0.47
First	11.0	3,168	0.79	0.48
First	11.5	3,312	1.24	-
First	12.0	3,456	0.92	0.64
First	12.5	3,600	0.90	0.68
First	13.0	3,744	0.33	0.53
First	13.5	3,888	0.43	0.51
First	14.0	4,032	0.57	0.51
First	14.1	4,061	0.50	0.55

Results:

Total Orthophosphate in Feed (as P) = 36.07 g

Phosphorus adsorbed during Run = 17.68 g

PERFORMANCE OF ACTIVATED ALUMINA COLUMNS

Column Number 3

Saturation Cycle Number 7

Date: January 9 - January 31, 1975

Activated Alumina in Column = 8,225 g

Unexpanded Bed Volume = 0.40 ft^3 (2.5 Igal)

Column Feed Rate = 0.50 Igpm

Nominal Contact Time = 5.0 minutes

Position of Column in Series	Run Time (Days)	Bed Volumes	Orthophosphate Concentration (mg P/l)	
			Column Feed	Column Effluent
Second	0.5	144	0.08	0.11
Second	0.75	216	0.08	0.12
Second	2.0	576	0.27	0.13
Second	3.0	864	0.32	0.15
Second	3.5	1,008	0.32	0.15
Second	4.0	1,152	0.30	0.13
Second	4.5	1,296	0.33	0.14
Second	5.0	1,440	0.41	0.18
Second	5.5	1,584	0.42	0.18
Second	6.0	1,728	0.45	0.20
Second	6.5	1,872	0.41	0.20
Second	7.0	2,016	0.43	0.21
Second	7.5	2,160	0.41	0.23
Second	8.5	2,448	0.42	0.21
Second	9.5	2,736	0.47	0.23
Second	10.0	2,880	0.46	0.24
Second	10.5	3,024	0.47	0.23
Second	11.0	3,168	0.48	0.25
Second	11.5	3,312	-	0.28
Second	12.0	3,456	0.64	0.32
Second	12.5	3,600	0.68	0.32
Second	13.0	3,744	0.53	0.34
Second	13.5	3,888	0.51	-
Second	14.0	4,032	0.51	0.35
Second	14.1	4,061	0.55	0.36
First	14.5	4,156	0.51	0.35
First	16.5	4,752	1.51	0.72
First	17.0	4,896	0.86	0.79
First	17.5	5,040	1.41	0.94
First	18.0	5,184	0.85	0.78
First	19.5	5,616	0.95	0.82
First	20.0	5,760	1.07	0.79
First	21.25	6,120	1.02	0.84
First	22.0	6,336	1.01	0.83

Results:

Total Orthophosphate in Feed (as P) = 44.28 g

Phosphorus adsorbed during Run = 15.87 g

PERFORMANCE OF ACTIVATED ALUMINA COLUMNS

Column Number 1

Saturation Cycle Number 10

Date: January 24 - January 31, 1975

Activated Alumina in Column = 7,740 g

Unexpanded Bed Volume = 0.40 ft^3 (2.5 Igal)

Column Feed Rate = 0.50 Igpm

Nominal Contact Time = 5 minutes

Position of Column in Series	Run Time (Days)	Bed Volumes	Orthophosphate Concentration (mg P/l)	
			Column Feed	Column Effluent
Second	2.0	576	0.72	0.23
Second	2.5	720	0.79	0.26
Second	3.0	864	0.94	0.32
Second	3.5	1,008	0.78	0.30
Second	5.0	1,440	0.82	0.36
Second	5.5	1,584	0.79	0.35
Second	6.75	1,944	0.84	0.44
Second	7.5	2,160	0.83	0.49

Results:

Total Orthophosphate in Feed (as P) = 19.42 g

Phosphorus adsorbed during Run = 11.57 g

APPENDIX III

SUMMARY OF REGENERATION DATA

REGENERATION OF ACTIVATED ALUMINA COLUMNS

Regeneration Number 1 Date: October 18, 1974

Column Regenerated: #1

Number of previous regenerations on column: None

Method: 100 Igal of 1.70 N NaOH Regenerant solution Continously recycled at 0.5 Igpm for 70 bed volumes through spent Activated Alumina column. Rinsed with 25 bed volumes of freshwater at 0.6 Igpm.

Analytical Results:

Sample Description	Normality (OH)	Concentration (mg/1)		
		Total Phosphorus	Aluminum	Iron
Initial Regenerant	1.70	0.44	1.0	0.39
Regenerant after 35 B.V.	-	37.5	250.0	3.7
Regenerant after 70 B.V.	1.60	38.0	300.0	4.3
Composite Rinse - Water Sample	-	25.0	100.0	0.45

Calculations:

I. Phosphorus Mass Balance:

Phosphorus recovered in Regenerant = 17.25 g
Phosphorus recovered in Rinsewater = 6.00 g
Total Phosphorus recovered = 23.25 g

Phosphorus adsorbed during Saturation Cycle = 32.44 g

Regeneration Efficiency = 71.7%

II. Activated Alumina Loss:

Aluminum recovered in Regenerant = 136.2 g
Aluminum recovered in Rinsewater = 25.0 g
Total Aluminum losses = 161.2 g

Activated Alumina (Al_2O_3) Loss = 304 g

Percentage Loss = 4.5%

III. Regenerant Loss:

Initial Regenerant Volume = 100 Igal

Initial Regenerant Strength = 1.70 N NaOH

Final Regenerant Volume = 100 Igal

Final Regenerant Strength = 1.60 N NaOH

Caustic Loss During Regeneration = 1,816 g

Percentage Loss = 5.9%

IV. Condition of Regenerated Column 1

Activated Alumina in column = 6,500 g

Residual Phosphorus present in column = 9.19 g

REGENERATION OF ACTIVATED ALUMINA COLUMNS

Regeneration Number 2 Date: October 23, 1974

Column Regenerated: #1 & #3 (Simultaneously)

Number of Previous Regenerations on column 1: One

on column 3: None

Method: Two spent Activated Alumina columns regenerated in series with same Regenerant solution as used for Regeneration 1. 100 Igal of 1.6 N NaOH Regenerant solution continuously recycled at 0.55 Igpm for 35 bed volumes (70 B.V. per column) through spent Activated Alumina columns in series. Rinsed with 10 bed volumes of freshwater (20 B.V. per column) at 0.6 Igpm until effluent pH reached 9.0.

Analytical Results:

Sample Description	Normality (OH)	Concentration (mg/l)		
		Total Phosphorus	Aluminum	Iron
Initial Regenerant Solution	1.60	38.0	300	4.3
Final Regenerant Solution	1.43	118.2	575	3.2
Rinsewater Samples After 1 B.V.	-	120.7	700	2.2
After 2.5 B.V.	-	40.5	250	2.7
After 5 B.V.	-	10.9	66	0.8
After 10 B.V.	-	1.6	17	0.2

Calculations:

I. Phosphorus Mass Balance:

Phosphorus recovered in Regenerant = 36.41 g
Phosphorus recovered in Rinsewater = 4.13 g
Total Phosphorus Recovered = 40.54 g

Phosphorus adsorbed during Saturation Cycle
Column 1 = 22.87 g
Column 3 = 31.90 g
Total Phosphorus adsorbed = 54.77 g

Regeneration Efficiency = 74.0%

II. Activated Alumina Loss:

Aluminum recovered in Regenerant = 0.00 g
Aluminum recovered in Rinsewater = 26.01 g
Total Aluminum Losses = 26.01 g
Activated Alumina (Al_2O_3) Losses = 49.13 g
Percentage Loss = 0.37%

III. Regenerant Loss:

Initial Regenerant Volume = 100 Igal
Initial Regenerant Strength = 1.39 N NaOH
Final Regenerant Volume = 100 Igal
Final Regenerant Strength = 1.23 N NaOH
Caustic Loss during Regeneration = 2,905 g NaOH
Percentage Loss = 11.5%

IV. Condition of Regenerated Columns:
(Based on assumption that regeneration process affected both columns equally)

	Column 1	Column 3
Activated Alumina in column:	6,335 g	6,635 g
Residual Phosphorus present in column:	40.07 g	28.28 g

REGENERATION OF ACTIVATED ALUMINA COLUMNS

Regeneration Number 3 Date: October 29, 1974

Column regenerated: #1 & #3 (Simultaneously)

Number of previous regenerations on Column 1: Two

on Column 3: One

Method: Two spent Activated Alumina columns regenerated in series with same Regenerant solution as used in Regeneration 2. Same Regeneration technique as used for Regeneration 2. Rinsed with 15 bed volumes of freshwater (30 B.V. per column) at 0.6 Igpm until effluent pH reached 9.0.

Analytical Results:

Sample Description	Normality (OH)	Concentration (mg/l)		
		Total Phosphorus	Aluminum	Iron
Initial Regenerant Solution	1.39	93.0	500	1.5
Final Regenerant Solution	1.23	146.0	500	1.2
Rinsewater Samples After 2.5 B.V.	-	70.0	300	1.8
5 B.V.	-	14.6	70	0.5
7.5 B.V.	-	4.2	20	0.1
10 B.V.	-	1.0	6	0.1
15 B.V.	-	0.3	4	0.2

Calculations:

I. Phosphorus Mass Balance:

Phosphorus recovered in Regenerant = 24.10 g
Phosphorus recovered in Rinsewater = 6.36 g

Total Phosphorus recovered = 30.46 g

Phosphorus adsorbed during Saturation Cycle

Column 1 = 46.18 g
Column 3 = 29.15 g

Total Phosphorus adsorbed = 75.33 g

Regeneration Efficiency = 40.4%

II. Activated Alumina Loss:

Aluminum recovered in Regenerant = 124.85 g

Aluminum recovered in Rinsewater = 26.42 g

Total Aluminum Losses = 151.27 g

Activated Aluminum (Al_2O_3) Losses = 285.7 g

Percentage Loss = 2.2%

III. Regenerant Loss:

Initial Regenerant Volume = 100 Igal

Initial Regenerant Strength = 1.60 N NaOH

Final Regenerant Volume = 100 Igal

Final Regenerant Strength = 1.43 N NaOH

Caustic Loss during Regeneration = 3,087 g NaOH

Percentage Loss = 10.6%

IV. Condition of Regenerated Columns:

(Based on assumption that regeneration process affected both columns equally)

	Column 1	Column 3
Activated Alumina in column:	6,360 g	6,660 g
Residual Phosphorus in column:	11.73 g	11.71 g

REGENERATION OF ACTIVATED ALUMINA COLUMNS

Regeneration Number 4 Date: November 5, 1974

Column Regenerated: #1

Number of previous regenerations on column: Three

Method: 100 Igal of 1.23 N NaOH Regenerant solution from Regeneration 3 continously recycled at 0.5 Igpm for 35 bed volumes through spent Activated Alumina column.

Rinsed with 25 bed volumes of freshwater at 0.6 Igpm until effluent pH reached 9.0

Analytical Results:

Sample Description	Normality (OH)	Concentration (mg/l)		
		Total Phosphorus	Aluminum	Iron
Initial Regenerant Solution	1.23	146.0	500	1.4
Final Regenerant Solution	1.17	190.0	500	1.3
Rinsewater Samples				
After 1 B.V.	-	188.0	475	0.4
After 5 B.V.	-	73.5	150	0.3
After 10 B.V.	-	17.0	41	2.5
After 15 B.V.	-	2.2	12	0.7
After 20 B.V.	-	4.3	2	0.3
After 27 B.V.	-	0.2	1	0.1

Calculations:

I. Phosphorus Mass Balance:

Phosphorus recovered in Regenerant = 19.98 g
Phosphorus recovered in Rinsewater = 7.54 g

Total Phosphorus recovered = 27.52 g

Phosphorus adsorbed during Saturation Cycle = 16.11 g

Regeneration Efficiency = 170.8%

II. Activated Alumina Loss:

Aluminum recovered in Regenerant = 0.00 g

Aluminum recovered in Rinsewater = 6.62 g

Total Aluminum Losses = 6.62 g

Activated Alumina (Al_2O_3) Loss = 12.5 g

Percentage Loss = 0.20%

III. Regenerant Loss:

Initial Regenerant Volume = 100 Igal

Initial Regenerant Strength= 1.23 N NaOH

Final Regenerant Volume = 100 Igal

Final Regenerant Strength = 1.17 N NaOH

Caustic Loss during Regeneration = 1,090 g NaOH

Percentage Loss = 4.9%

IV. Condition of Regenerated Column:

Activated Alumina in column = 6,320 g

Residual Phosphorus present in column = 28.71 g

REGENERATION OF ACTIVATED ALUMINA COLUMNS

Regeneration Number 5 Date: November 8, 1974

Column regenerated : #3

Number of previous regenerations on column: Two

Method: 10 Igal (5 B.V.) fresh 0.97 N NaOH Regenerant solution continuously recycled at 0.5 Igpm for 35 bed volumes through spent Activated Alumina column. Rinsed with 23 bed volumes of freshwater at 0.5 Igpm until effluent pH reached 9.0

Analytical Results:

Sample Description	Normality (OH)	Concentration (mg/l) Total Phosphorus	Aluminum	Iron
Initial Regenerant Solution	0.97	0.1	< 1	1.65
Column Effluent				
After 1 B.V.	-	104.5	203	1.25
After 4 B.V.	-	124.5	300	0.90
After 8 B.V.	-	121.0	300	1.50
After 12 B.V.	-	118.2	300	0.80
After 16 B.V.	-	112.7	325	0.90
After 20 B.V.	-	108.0	400	0.80
After 24 B.V.	-	98.0	425	0.75
After 28 B.V.	-	81.0	450	0.85
After 32 B.V.	-	72.9	450	0.55
After 35 B.V.	-	71.0	463	0.90
Final Regenerant Solution	0.65	70.1	450	1.30
Rinsewater Samples				
After 1 B.V.	-	42.3	325	1.95
After 4 B.V.	-	7.9	85	0.60
After 8 B.V.	-	0.5	13	0.15
After 12 B.V.	-	0.12	4	0.10
After 16 B.V.	-	0.19	2	0.10
After 23 B.V.	-	0.16	2	0.10

Calculations:

I. Phosphorus Mass Balance:

Phosphorus recovered in Regenerant = 3.94 g
Phosphorus recovered in Rinsewater = 0.95 g
Total Phosphorus recovered = 4.89 g
Phosphours adsorbed during Saturation Cycle = 12.14 g
Regeneration Efficiency = 40.3%

II. Activated Alumina Loss:

Aluminum recovered in Regenerant = 20.43 g
Aluminum recovered in Rinsewater = 9.50 g
Total Aluminum Losses = 29.93 g
Activated Alumina (Al_2O_3) Loss = 56.5 g
Percentage Loss = 0.85%

III. Regenerant Loss:

Initial Regenerant Volume = 10 Igal
Initial Regenerant Strength = 0.97 N NaOH
Final Regenerant Volume = 10 Igal
Final Regenerant Strength = 0.65 N NaOH
Caustic Loss during Regeneration = 582 g
Percentage Loss = 33.0%

IV. Condition of Regenerated Column:

Activated Alumina in column = 6,580 g
Residual Phosphorus present in column = 35.53 g

REGENERATION OF ACTIVATED ALUMINA COLUMNS

Regeneration Number 6 Date: November 29, 1974

Column regenerated: #1

Number of previous regenerations on column: Four

Method: 10 Igal (5 B.V.) fresh 1.97 N NaOH Regenerant solution continuously recycled at 0.5 Igpm for 35 bed volumes through spent Activated Alumina column. Rinsed with 16 bed volumes of freshwater at 0.5 Igpm until effluent pH reached 9.0.

Analytical Results:

Sample Description	Normality (OH)	Concentration (mg/l) Total Phosphorus	Aluminum
Initial Regenerant Solution	1.97	0.15	2.5
Column Effluent			
After 1 B.V.	-	81.8	-
After 4 B.V.	-	112.7	225
After 8 B.V.	-	122.0	288
After 12 B.V.	-	133.5	305
After 16 B.V.	-	135.7	330
After 20 B.V.	-	138.5	360
After 24 B.V.	-	145.6	400
After 28 B.V.	-	146.8	370
After 30 B.V.	-	150.9	330
Final Regenerant Solution	1.47	149.5	330
Rinsewater Samples			
After 4 B.V.	-	20.5	62
After 8 B.V.	-	1.33	10
After 12 B.V.	-	0.13	1
After 16 B.V.	-	0.11	1

Calculations:

I. Phosphorus Mass Balance:

Phosphorus recovery in Regenerant = 6.79 g
Phosphorus recovery in Rinsewater = 2.99 g
Total Phosphorus recovered = 9.78 g
Phosphorus adsorbed during Saturation Cycle = 11.86 g
Regeneration Efficiency = 82.5%

II. Activated Alumina Loss:

Aluminum recovered in Regenerant = 14.98 g
Aluminum recovered in Rinsewater = 7.36 g
Total Aluminum Losses = 22.34 g
Activated Alumina (Al_2O_3) Loss = 42.2 g
Percentage Loss = 0.67 %

III. Regenerant Loss:

Initial Regenerant Volume = 10 Igal
Initial Regenerant Strength = 1.97 N NaOH
Final Regenerant Volume = 10 Igal
Final Regenerant Strenght = 1.47 N NaOH
Caustic Loss during Regeneration = 908 g NaOH
Percentage Loss = 25.4%

IV. Condition of Regenerated Column:

Activated Alumina in column = 6,280 g
Residual Phosphorus present in column = 26.74 g

REGENERATION OF ACTIVATED ALUMINA COLUMNS

Regeneration Number 7 Date: December 4, 1974

Column regenerated: #3

Number of previous regenerations on column: Three

Method: 75 Igal of lime regenerated Caustic solution continuously recycled at 0.5 Igpm for 35 bed volumes.
Rinsed with 15 bed volumes of freshwater at 0.5 Igpm until effluent pH reached 9.0

Analytical Results:

Sample Description	Normality (OH)	Concentration (mg/l) Total Phosphorus	Aluminum	Calcium
Initial Regenerant Solution	1.14	91.5	360	50
Final Regenerant Solution	1.06	117.5	380	45
Rinsewater Samples				
After 1 B.V.	-	61.4	250	-
After 4 B.V.	-	6.9	39	-
After 8 B.V.	-	0.8	10	-
After 12 B.V.	-	0.1	3	-
After 15 B.V.	-	0.1	2	-

Calculations:

I. Phosphorus Mass Balance:

Phosphorus recovered in Regenerant = 8.68 g

Phosphorus recovered in Rinsewater = 1.14 g

Total Phosphorus Recovered = 9.82 g

Phosphorus adsorbed during Saturation Cycle = 12.63 g

Regeneration Efficiency = 77.8%

II. Activated Alumina Loss:

Aluminum recovered in Regenerant = 6.67 g

Aluminum recovered in Rinsewater = 4.55 g

Total Aluminum Losses = 11.22 g

Activated Alumina (Al_2O_3) Loss = 21.2 g

Percentage Loss = 0.32 %

III. Regenerant Loss:

Regenerant Volume = 20 Igal

Initial Regenerant Strength = 0.90 N NaOH

Final Regenerant Strength = 0.85 N NaOH

Caustic Loss during Regeneration = 182 g NaOH

Percentage Loss = 5.6%

IV. Condition of Regenerated Column:

Activated Alumina in column = 6,265 g

Residual Phosphorus present in column = 36.92 g

REGENERATION OF ACTIVATED ALUMINA COLUMNS

Regeneration Number 8 Date: December 13, 1974

Column regenerated: #1

Number of previous regenerations on column: Five

Method: 20 Igal (10 B.V.) aliquot of Regenerant solution used for Regeneration 7, after second lime treatment process, pumped once through spent Activated Alumina column at 0.5 Igpm. Rinsed with 15 bed volumes of freshwater at 0.5 Igpm until effluent pH reached 9.0.

Analytical Results:

Sample Description	Normality (OH)	Concentration (mg/l) Total Phosphorus	Aluminum	Calcium
Initial Regenerant Solution	1.06	13.7	36	70
Composite Column Effluent				
After 1 B.V.	-	134.0	190	-
After 2.5 B.V.	-	117.5	128	-
After 3.8 B.V.	-	100.0	116	-
After 7.5 B.V.	-	80.0	74	-
After 10.0 B.V.	0.98	61.5	74	55
Rinsewater Samples				
After 1 B.V.	-	32.6	80	-
After 4 B.V.	-	9.4	48	-
After 8 B.V.	-	1.7	14	-
After 12 B.V.	-	0.3	9	-
After 15 B.V.	-	0.1	7	-

Calculations:

I. Phosphorus Mass Balance:

Phosphorus recovered in Regenerant = 4.34 g

Phosphorus recovered in Rinsewater = 0.86 g

Total Phosphorus recovered = 5.20 g

Phosphorus adsorbed during Saturation Cycle = 10.67 g

Regeneration Efficiency = 48.7%

Calculations:

II. Activated Alumina Loss:

Aluminum recovered in Regenerant = 3.45 g

Aluminum recovered in Rinsewater = 2.47 g

Total Aluminum Losses = 5.92 g

Activated Alumina (Al_2O_3) loss = 11.2 g

Percentage Loss = 0.18%

III. Regenerant Loss:

Regenerant Volume = 20 Igal

Initial Regenerant Strength = 1.06 N NaOH

Final Regenerant Strength = 0.98 N NaOH

Caustic Loss during Regeneration = 291 g NaOH

Percentage Loss = 7.6%

IV. Condition of Regenerated Column:

Activated Alumina in column = 6,270 g

Residual Phosphorus present in column = 32.21 g

REGENERATION OF ACTIVATED ALUMINA COLUMNS

Regeneration Number 9 Date: December 24, 1974

Column regenerated: #3

Number of previous regenerations on column: Four

Method: Same 20 Igal (10 B.V.) aliquot of twice time treated Regeneration 8, pumped once through spent Activated Alumina column at 0.5 Igpm.

Rinsed with 15 bed volumes of freshwater at 0.5 Igpm until effluent pH reached 9.0.

Analytical Results:

Sample Description	Normality (OH)	Concentration (mg/l)		
		Total Phosphorus	Aluminum	Calcium
Initial Regenerant Solution	0.98	61.5	74	55
Final Regenerant Solution	0.90	115.0	80	50
Rinsewater Samples				
After 1 B.V.	-	91.0	116	-
After 2 B.V.	-	55.8	82	-
After 4 B.V.	-	16.3	30	-
After 8 B.V.	-	0.8	2	-
After 10 B.V.	-	0.5	<1	-
After 15 B.V.	-	0.1	<1	-

Calculations:

I. Phosphorus Mass Balance:

Phosphorus recovered in Regenerant = 4.89 g

Phosphorus recovered in Rinsewater = 1.73 g

Total Phosphorus recovered = 6.62 g

Phosphorus adsorbed during Saturation Cycle = 15.92 g

Regeneration Efficiency = 41.6%

II. Activated Alumina Loss:

Aluminum recovered in Regenerant = 0.54 g

Aluminum recovered in Rinsewater = 3.21 g

Total Aluminum Losses = 3.75 g

Calculations:

III. Regenerant Loss:

Initial Regenerant Volume = 75 Igal

Initial Regenerant Strength = 1.14 N NaOH

Final Regenerant Volume = 75 Igal

Final Regenerant Strength = 1.06 N NaOH

Caustic Loss during regeneration = 1,090 g NaOH

Percentage Loss = 7.0 %

IV. Condition of Regenerated Column:

Activated Alumina in column = 6,560 g

Residual Phosphorus present in column = 38.34 g

REGENERATION OF ACTIVATED ALUMINA COLUMN

Regeneration Number 10 Date: December 28, 1974

Column regenerated: #1

Number of previous regenerations on column: Six

Method: 20 Igal (10 B.V.) of Regenerant solution after third time treatment, pumped once through spent Activated Alumina column at 0.5 Igpm.

Rinsed with 15 bed volumes of freshwater at 0.5 Igpm until effluent pH reached 9.0.

Analytical Results:

Sample Description	Normality (OH)	Concentration (mg/l)		
		Total Phosphorus	Aluminum	Calcium
Initial Regenerant Solution	0.90	3.1	68	60
Final Regenerant Solution	0.85	69.8	79	55
Rinsewater Samples				
After 1 B.V.	-	57.5	79	-
After 2 B.V.	-	37.5	58	-
After 4 B.V.	-	6.5	15	-
After 8 B.V.	-	0.2	1	-

Calculations:

I. Phosphorus Mass Balance:

Phosphorus recovered in Regenerant = 6.06 g

Phosphorus recovered in Rinsewater = 1.70 g

Total Phosphorus recovered = 7.76 g

Phosphorus adsorbed during Saturation Cycle = 12.47 g

Regeneration Efficiency = 62.2%

II. Activated Alumina Loss:

Aluminum recovered in Regenerant = 1.00 g

Aluminum recovered in Rinsewater = 1.86 g

Total Aluminum Losses = 2.86 g

Activated Alumina (Al_2O_3) Loss = 5.4 g

Percentage Loss = 0.09%

Activated Alumina (Al_2O_3) Loss = 7.1 g

Percentage Loss = 0.11 %

III. Regenerant Losses:

Regenerant Volume = 20 Igal

Initial Regenerant Strength = 0.98 N NaOH

Final Regenerant Strength = 0.90 N NaOH

Caustic Loss during regeneration = 2909 NaOH

Percentage Loss = 8.2%

IV. Condition of Regenerated Column:

Activated Alumina in column = 6,550 g

Residual Phosphorus present in column = 47.64 g

REGENERATION OF ACTIVATED ALUMINA COLUMNS

Regeneration Number 11 Date: January 9, 1975

Column regenerated: #1 & #3 (simultaneously)

Number of previous regenerations on Column 1: Seven

on Column 5: Five

Method: 80 Igal of regenerant solution as used for Regeneration 11: through two spent Activated Alumina columns in series at 0.5 Igpm for 17.5 bed volumes (35 B.V. per column). Rinsed with 12 bed volumes of freshwater (24 B.V. per column) at 0.5 Igpm until effluent pH reached 9.0.

Analytical Results:

Sample Description	Normality (OH)	Concentration (mg/l)	
		Total Phosphorus	Aluminum
Initial Regenerant Solution	1.15	0.15	1.0
Final Regenerant Solution	1.05	53.1	48.5
Rinsewater Samples			
After 1 B.V.	-	46.8	138.0
After 2 B.V.	-	22.0	88.0
After 4 B.V.	-	8.7	42.5
After 6 B.V.	-	5.1	28.0
After 8 B.V.	-	0.2	5.0
After 12 B.V.	-	0.1	1.8

Calculations:

I. Phosphorus Mass Balance:

Phosphorus recovered in Regenerant = 19.25 g

Phosphorus recovered in Rinsewater = 1.38 g

Total Phosphorus recovered = 20.63 g

Phosphorus adsorbed during Saturation Cycle:

Column 1 = 14.34 g

Column 3 = 19.01 g

Total Phosphorus Adsorbed = 33.35 g

Regeneration Efficiency = 61.9%

II. Activated Alumina Loss:

Aluminum recovered in Regenerant = 17.25 g
Aluminum recovered in Rinsewater = 7.83 g
Total Aluminum Loss = 25.08 g
Activated Alumina (Al_2O_3) Loss = 47.4 g
Percentage Loss = 0.37%

III. Regenerant Loss:

Regenerant Volume = 80 Igal.
Initial Regenerant Strength = 1.15 N NaOH
Final Regenerant Strength = 1.05 N NaOH
Caustic Loss during regeneration = 1,453 g NaOH
Percentage Loss = 8.7 %

IV. Condition of Regenerated Columns:

(Assuming that regeneration process affected both columns equally).

	Column 1	Column 3
Activated Alumina in Column	6,240 g plus 1,700 g fresh Al_2O_3	6,525 g plus 1,700 g fresh Al_2O_3
Residual Phosphorus present in column	42.29	54.99

REGENERATION OF ACTIVATED ALUMINA COLUMNS

Regeneration Number 12 Date: January 24, 1975

Column Regenerated: #1

Number of Previous Regenerations on Column: Eight

Method: 80 Igal of Regenerant solution as used for Regeneration 11:

- Initial 8 bed volumes (20 Igal) pumped once through column at 0.5 Igpm.
- Recovered Regenerant solution mixed with remaining 60 Igal of original solution.
- 80 Igal of Regenerant continuously recycled at 0.5 Igpm for 12 bed volumes through column.

Rinsed with 12 bed volumes of freshwater at 0.5 Igpm until effluent pH reached 9.0.

Analytical Results:

Sample Description	Normality (OH)	Concentration (mg/l) Total Phosphorus	Aluminum
Initial Regenerant Solution	1.00	50.8	112
Column Effluent			
After 1 B.V.	-	155.0	300
After 2 B.V.	-	166.0	363
After 3 B.V.	-	167.0	383
After 4 B.V.	-	165.0	350
After 6 B.V.	-	157.5	350
After 8 B.V.	-	155.0	345
Final Regenerant Solution	0.90	86.5	388
Rinsewater Samples			
After 1 B.V.	-	225.0	562
After 3 B.V.	-	62.8	122
After 4 B.V.	-	32.6	85
After 8 B.V.	-	12.8	36
After 12 B.V.	-	3.6	20

Calculations:

I. Phosphorus Mass Balance:

Phosphorus recovered in Regenerant = 12.98 g

Phosphorus recovered in Rinsewater = 5.68 g

Total Phosphorus recovered = 18.66 g

Phosphorus adsorbed during Saturation Cycle = 17.68 g

Regeneration Efficiency =105.5 %

II. Aluminum Loss:

Aluminum recovered in Regenerant = 100.24 g

Aluminum recovered in Rinsewater = 14.87 g

Total Aluminum Loss = 115.11 g

Activated Alumina (Al_2O_3) Loss = 217.4 g

Percentage Loss = 2.7%

III. Regenerant Loss:

Regenerant Volume = 80 Igal

Initial Regenerant Strength = 1.00 N NaOH

Final Regenerant Strength = 0.90 N NaOH

Caustic Loss during regeneration = 1.453 g NaOH

Percentage Loss = 10.0 %

IV. Condition of Regenerated Column:

Activated Alumina in column = 7,740 g

Residual Phosphorus present in column = 41.31 g

REGENERATION OF ACTIVATED ALUMINA COLUMNS

Regeneration Number 13 Date: January 31, 1975

Column regenerated: #1 & #3 (simultaneously)

Number of previous regenerations on Column 1 : Nine

on Column 2: Six

Method: 80 Igal of Regenerant from Regeneration 12 made up to 2.1 N NaOH with 5 Igal commercial caustic solution.

6 bed volumes (12 B.V. per column) pumped once through spent Activated Alumina column in series at 0.5 Igpm.

Rinsed with 6 bed volumes (12 B.V. per column) at 0.5 Igpm until effluent pH reached 9.0.

Analytical Results:

Sample Description	Normality (OH)	Concentration (mg/l)	
		Total Phosphorus	Aluminum
Initial Regenerant Solution	2.10	80.5	150
Composite Column Effluent			
After 0.5 B.V.	-	426.0	570
After 1 B.V.	-	461.5	680
After 1.5 B.V.	-	410.0	620
After 3 B.V.	-	331.5	600
After 4.5 B.V.	-	314.0	600
After 6 B.V.	1.95	247.5	538
Rinsewater Sample			
After 0.5 B.V.	-	212.5	1100
After 1.0 B.V.	-	152.5	-
After 1.5 B.V.	-	96.2	310
After 2.0 B.V.	-	86.0	338
After 3.0 B.V.	-	38.5	-
After 4.0 B.V.	-	22.5	95
After 6.0 B.V.	-	12.3	51

Calculations:

I. Phosphorus Mass Balance:

Phosphorus recovered in Regenerant = 22.75 g

Phosphorus recovered in Rinsewater = 9.22 g

Total Phosphorus recovered = 31.97 g

Phosphorus Adsorbed during Saturation Cycle

Column 1 = 11.57 g

Column 2 = 15.87 g

Total Phosphorus adsorbed = 27.44 g

Regeneration Efficiency = 116.5 %

II. Activated Alumina Loss:

Aluminum recovered in Regenerant = 51.92 g

Aluminum recovered in Rinsewater = 47.22 g

Total Aluminum Loss = 99.14 g

Activated Alumina (Al_2O_3) Loss =187.3 g

Percentage Loss = 1.17 %

III. Regenerant Loss:

Regenerant Volume = 30 Igal

Initial Regenerant Strength = 2.10 N NaOH

Final Regenerant Strength = 1.95 N NaOH

Caustic Loss during regeneration = 817 g NaOH

Percentage Loss = 7.1 %

IV. Condition of Regenerated Columns:

(Assuming that Regeneration process affected both columns equally)

	Column 1	Column 2
Activated Alumina in column:	7,645	8,130

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